PB88-120704

National Dioxin Study Tier 4
Combustion Sources: Engineering Analysis Report

Radian Corp., Research Triangle Park, NC

Prepared for

Environmental Protection Agency
Research Triangle Park, NC

Sep 87

U.S. Department of Commerce
National Technical Information Service
NTIS

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO.
EPA-450/4-84-014h

2.

3. RECIPIENT'S ACCESSION NO.
PB88 120704/AS

4. TITLE AND SUBTITLE
National Dioxin Study Tier 4 - Combustion Sources
Engineering Analysis Report

5. REPORT DATE
September 1987

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
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8. PERFORMING ORGANIZATION REPORT NO.
87-203-061-07-09

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Radian Corporation
P.O. Box 13000
Research Triangle Park, NC 27709

10. PROGRAM ELEMENT NO.

11. CONTRACT/GRANT NO.
68-02-3889

12. SPONSORING AGENCY NAME AND ADDRESS
Environmental Protection Agency
Office of Air Quality Planning and Standards
Monitoring and Data Analysis Division
Research Triangle Park, NC 27711

13. TYPE OF REPORT AND PERIOD COVERED
Final

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

EPA Project Officer: William B. Kuykendal

16. ABSTRACT

This report summarizes the complete results of Tier 4 (combustion sources) of the National Dioxin Study. The purpose of the Tier 4 study was to address the following questions: Do combustion sources emit dioxin? If so, how much? Are these emissions significant? A secondary objective was to attempt to determine what combustion parameters affect dioxin emissions and to determine the effectiveness of conventional control devices for controlling dioxin emissions.

The report presents the results of a literature review containing 249 references, the results of a stack sampling program, and the results of an ash sampling program. The stack sampling program produced valid data from 12 sites covering 8 combustion source categories. Data are presented for dioxin (tetra through octa homologue + 2378-TCDD) and furan (tetra through octa homologue +2378-TCDF) emissions as well as combustion conditions. Where possible, data were obtained before and after control devices. Ash samples were collected from 74 sites covering 22 combustion source categories. Dioxin and furan data are presented for the ash data. Various data correlations are presented.

Dioxins and furans were detected in the stack emissions for all 12 sites tested. These emissions varied over 5 orders of magnitude. About one half of the ash samples contained dioxins and furans.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Emissions Combustion Sources Dioxin Furans 2,3,7,8 Tetrachlorodibenzo-p-dioxin	Air Pollution Emissions Data	

18. DISTRIBUTION STATEMENT Release Unlimited	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 390
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

PB88-120704

United States
Environmental Protection
Agency

Office of Air Quality
Planning and Standards
Research Triangle Park NC 27711

EPA-450/4-84-014h
September 1987

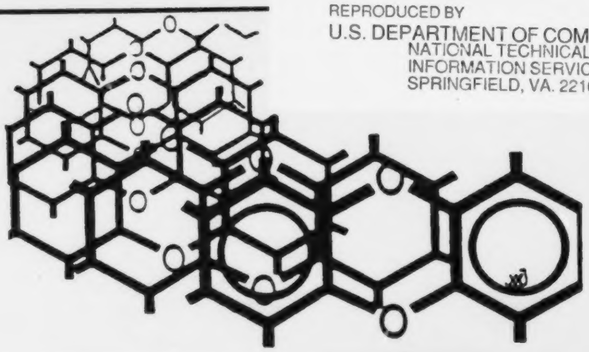
Air

EPA

National Dioxin Study Tier 4 — Combustion Sources

Engineering Analysis Report

REPRODUCED BY
U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL
INFORMATION SERVICE
SPRINGFIELD, VA. 22161



EPA-450/4-84-014h

National Dioxin Study Tier 4 — Combustion Sources

Engineering Analysis Report

By
Radian Corporation
Research Triangle Park, NC 27709

Contract No. 68-02-3889

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office Of Air And Radiation
Office Of Air Quality Planning And Standards
Research Triangle Park, NC 27711

September 1987

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This report has been reviewed by the Office Of Air Quality Planning And Standards, U.S. Environmental Protection Agency, and approved for publication as received from the contractor. Approval does not signify that the contents necessarily reflect the views and policies of the Agency, neither does mention of trade names or commercial products constitute endorsement or recommendation for use.

EPA-450/4-84-014h

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CHAPTER 1
EXECUTIVE SUMMARY

The Air Management Technology Branch of the U. S. Environmental Protection Agency's (EPA) Office of Air Quality Planning and Standards (OAQPS) was responsible for implementing Tier 4 of the National Dioxin Study. Radian Corporation, under task order contract, provided technical support for this program. The technical support included developing literature surveys, preparing sampling protocols, conducting stack tests, coordinating ash sampling efforts and preparing this and other reports.

The National Dioxin Study was focused on the study of chlorinated dibenzo-p-dioxins (CDD's), and in particular on polychlorinated dibenzo-p-dioxins containing four or more chlorine atoms (PCDD's). The acronyms CDD and PCDD will be used in this report to denote these species. Section 2.3.2 contains a complete explanation of the nomenclature used in this report.

The primary objective of Tier 4 was to study combustion processes as potential sources of PCDD emissions and the related compounds chlorinated dibenzofurans (CDF's). The following questions were addressed:

- Do combustion sources emit PCDD's?
- If so, how much?
- Are these emissions significant?

A secondary objective of the Tier 4 sampling program was to attempt to determine what factors affect PCDD/PCDF emissions, and to determine the effectiveness of conventional control devices for controlling PCDD/PCDF emissions.

The Tier 4 study began in November 1983 with an extensive literature survey. The purposes of the literature survey were to 1) summarize previous research done on emissions of CDD's and chlorinated dibenzofurans (CDF's) from combustion processes, and 2) summarize available CDD and CDF emissions data from combustion processes. After the literature survey was completed, emissions source testing and combustion ash sampling programs were initiated under

Tier 4 to investigate the hypotheses identified in the literature. This report summarizes the data gathered during the Tier 4 study and provides a data analysis which is primarily intended to illustrate the extent to which combustion sources emit CDD's.

The literature survey identified 13 broadly defined source categories (described in Section 3.1) for which some PCDD and polychlorinated dibenzofuran (PCDF) emissions data had been collected prior to the Tier 4 study. Those source categories for which stack emissions data were available are shown in Table 1-1 along with the source categories tested under Tier 4. The data presented reflects as-measured and as-reported concentrations. Normalization to a reference oxygen level has not been made since insuffient data were available. The literature survey indicated that municipal solid waste incinerators were the most frequently tested source category and had the highest levels of PCDD's and PCDF's in stack gas emissions. Commercial boilers co-firing spiked waste oil had the next highest PCDD concentrations in stack gas emissions, followed by emissions from one tested unit combusting pentachlorophenol-treated wood.

PCDD's and PCDF's were not found in stack emissions from all combustion sources for which data were reported in the literature. Two utility boilers firing PCB-spiked waste oil, a lime kiln, a coal-fired utility boiler and the incinerator ship M/T Vulcanus were all tested and had less than detectable PCDD emissions. In general, the literature survey showed that where combustion sources did emit PCDD's or PCDF's, these emissions appear to be dependent on the types of fuel or waste being fired and whether or not the combustion units were designed and operated specifically to achieve the destruction of compounds such as PCDD's and PCDF's.

Emissions from combustion devices burning clean fuel such as natural gas and distillate oil have not been adequately characterized. However, these sources are unlikely to emit high levels of PCDD/PCDF's because of the small amounts of precursors, specifically chlorine, present in the fuel. Some high temperature (above 2,500^{0}F firebox temperature) combustion sources such as utility boilers and cement kilns were also found to emit less than detectable amounts of PCDD/PCDF under the test conditions.

TABLE 1-1. SUMMARY OF PCDD/PCDF STACK EMISSIONS BY SOURCE CATEGORY

Source Category	Number of Units Tested[a]		Range of PCDD Emissions (as measured, ng/m^3)	Range of PCDF Emissions (as measured, ng/m^3)
	Tier 4	Literature		
1. Municipal Waste Incinerators				
European	0	8	71 - 48,997	37 - 9,831
U.S. and Canada	0	10	3.3 - 11,686	8.5 - 22,000
2. Boilers Cofiring Waste				
Commercial	0	3	1,400 - 17,000	170
Industrial	0	5	<0.002[b] - 76.4	<0.002 - 5.5
3. Secondary Copper Cupola Furnace	1	0	11,900	60,700
4. Wood Combustion				
PCP-Treated Wood	0	2	<17[c] - 1,520	<17[c] - 587
Salt-Laden Wood-Fired Boiler	1	0	195	83.2
5. Sewage Sludge Incinerators	3	2	ND[d] - 812	ND[d] - 1,374
6. Wire Reclamation Incinerator (wire and transformer feed)	1	0	704	866
7. Industrial Solid Waste Incinerator	1	0	625	2,390
8. Wire Reclamation Incinerator (wire-only feed)	1	0	173	305
9. Hospital Incinerators	0	4	15 - 69	25 - 156
10. Hazardous Waste Incinerators				
Rotary Kiln	0	2	7.7 - 8.6	11.2 - 19
11. Drum & Barrel Reclamation Incinerator	1	0	5	27
12. Carbon Regeneration Furnace				
without Afterburner	0	1	0.18	0.3
with Afterburner	1	1	1.6 - 3.7	0.05 - 3.3
13. Black Liquor Boiler	3	0	0.8 - 2.9	0.6 - 2.1
14. Cement Kilns	0	3	<1[e] - 1.35	<1[e] - 0.74
15. Lime Kilns	0	1	<0.34 - <2.0	---
16. Utility Boiler Co-firing Waste	0	1	<0.031 - <0.10	<0.31 - <0.10
17. Fossil Fuel Combustion				
Coal-Fired Utility	0	4	<0.10 - <0.70	<0.10 - <0.70
Pulverized Coal	0	1	<4.2 - <7.9[f]	<0.67 - <1.3[f]
Oil-Fired Utility	0	1	<4.2 - <7.9[f]	<0.67 - <1.3[f]
18. Incinerator Ship	0	1	<0.0009 - <0.086[g]	<0.3 - <3.0

"---" means data not reported.

[a] Analytical data for a noncatalytic woodstove tested under Tier 4 were not reported.

[b] Numbers preceded by "<" indicate detection limits.

[c] Detection limits reported in terms of ppb (by volume).

[d] ND = not detected. Detection limits not reported.

[e] Detection limits reported in terms of ng/ul of sample injected into GC-MS for analysis.

[f] 2378 TCDD/2378 TCDF scan only.

[g] Detection limits reported in terms of ng/ml injected into GC-MS for analysis.

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The literature review indicated that several factors affect CDD/CDF emissions. These factors include the PCDD content of the feed, precursor content of the feed, chlorine content of the feed, combustion device temperature, combustion device residence time, combustion device oxygen availability, feed processing and supplemental fuel. These factors were addressed during the analysis of the Tier 4 data. As a whole, the statistical analysis did not provide quantitative relationships between CDD/CDF emissions and the independent factors considered. However, the analysis did identify a few potentially meaningful associations, including strong inverse associations between maximum measured combustion chamber temperature and total CDD/CDF. Composition of feed materials also influenced the magnitude of CDD/CDF emissions. These analyses are discussed in Chapter 6.

In conjunction with the literature survey, a source test plan was developed to expand the PCDD/PCDF emissions data base and to address the objectives of the Tier 4 program. Potential source categories to be included in the test program were identified by a ranking process based on the potential to emit PCDD's. The ranking was subjective and was based on many factors, including potential for PCDD content in the feed, the size of the source category, the presence of precursors in the feed, typical operating conditions of the combustion device and the number of previous source tests performed. Specific test sites within a source category were selected based on inputs from State pollution control agencies and results of on-site pre-test surveys. A total of 31 pre-test surveys were conducted to select the 13 Tier 4 test sites.

The 13 source tests were conducted during 1984 and 1985. Nine different types of combustion units were tested. These included three sewage sludge incinerators, three black liquor boilers, one wire reclamation incinerator, one industrial solid waste incinerator, one carbon regeneration furnace, one secondary copper blast furnace, one wood-fired boiler, one drum and barrel reclamation furnace, and one residential woodstove.

The Modified Method 5 (MM5) protocol specified by the December 1984 Environmental Standards Workshop was followed as closely as possible for

PCDD/PCDF sampling.[a] Three MM5 test runs were performed at each test site (except for the wire reclamation incinerator site, where six MM5 runs were performed). At a minimum, MM5 sampling of the outlet emissions stream was performed at each test site. Where feasible, MM5 sampling was also performed at the inlet to the control devices in order to obtain PCDD/PCDF removal efficiency data. MM5 sample components were analyzed for PCDD and PCDF content using high resolution gas chromatography/high resolution mass spectrometry. While the sampling and analysis methods used in this study were state-of-the-art, they are nevertheless evolutionary. During the course of the study, it was sometimes found that the analysis methods could not cope with high levels of interfering contamination from other pollutants. This caused difficulty in achieving the desired validity and precision of results. Also, the MM5 stack sampling method is currently undergoing validation testing. Preliminary results indicate that under some conditions, recovery efficiencies from the sampling method may be low and variable, with possibly less than half of the CDDs and CDFs in the stack emissions being collected by the stack sampling method. Additional validation testing is currently underway.

Combustion gases were continuously monitored for oxygen, CO, CO_2, total hydrocarbons (THC), NO_x, and SO_2 to document the stability of combustion conditions at each site. In addition, at some or all of the sites the following types of sampling were performed: feed sampling, hydrochloric acid emissions sampling, combustion air sampling, combustion ash sampling, soil sampling, and auxiliary process sampling.

Table 1-1 summarizes the range of PCDD/PCDF emissions data for the 18 source categories that have been sampled to date, either by the Tier 4 program or those identified in the literature. The results of the Tier 4 sampling and analysis showed that all combustion sources tested under Tier 4 emit PCDD's and PCDF's. The total PCDD emissions vary over four orders of magnitude between the test sites. Emissions of 2378-TCDD generally account for less than 1 percent of the total PCDD emissions. PCDD and PCDF emissions are usually on the same order of magnitude.

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[a] Analytical Procedures to Assay Stack Effluent Samples and Residual Combustion Products for Polychlorinated Dibenzo-p-Dioxins (PCDD) and Polychlorinated Dibenzofurans (PCDF). Prepared by Group C- Environmental Standards Workshop. Sept. 18, 1984, revised Dec. 31, 1984.

An engineering analysis of the Tier 4 test data and equivalent data obtained from the literature review was performed. The analysis attempted to address some of the secondary objectives of Tier 4, including:

- o What factors affect PCDD/PCDF emissions?
- o How effective are conventional emissions control devices for controlling PCDD/PCDF emissions?

Unfortunately, the data set was too small to allow these questions to be completely addressed and in addition, the analytical results for PCDD and PCDF are not exact (± 50%). However, indications of factors that can have a significant influence on PCDD emissions may be obtained by studying the composite results from the literature survey and testing effort. At the very broadest level of inspection the data obtained from the literature and Tier 4 indicate the following:

- o The highest PCDD emissions concentrations appear to be associated with low temperature combustion processes whose function is to recover energy or other resources (e.g., metal values) by combustion of waste materials. Examples of these types of processes are municipal solid waste incinerators and the secondary copper blast furnace.
- o Combustion temperature alone appears to have an inverse association with the total PCDD emission levels. This is supported by an analysis of the municipal solid waste incinerator data presented in 6.2.3. This is not an unexpected effect, since lower combustion temperatures lead to increased emissions of products of incomplete combustion, while high temperatures coupled with long residence times have been used to destroy hazardous wastes at very high efficiencies.
- o The composition of feed materials is also expected to have a marked influence on the magnitude of PCDD/PCDF emissions and this is

partially supported by the Tier 4 results. There have been a number of theories advanced in the literature concerning which components of the feed contribute to PCDD/PCDF formation. Components most often identified are specific precursors (chlorobenzenes, chlorophenols, chlorinated biphenyls), organic chlorine or total chlorine. In addition, several authors have suggested that lignin and plastics content may also be important. Feed materials from some of the Tier 4 test sites were analyzed for specific precursors, total organic halogens (TOX), and total chloride content. Of these factors, TOX analysis showed the strongest association with total PCDD emissions. The amount of plastics or lignins in each feed material was not specifically analyzed for. However, the highest PCDD emissions were measured at sites containing plastics in the feed.

There are very few data in the literature concerning control of PCDD/PCDF emissions since most sampling efforts have focused on emissions at the stack and not at the control device inlet. Several approaches to controlling PCDD emissions have been postulated. These include operating the combustion device to minimize PCDD emissions, use of high temperature/long residence time afterburners or secondary combustion chambers to reduce PCDD, or use of conventional particulate control devices.

PCDD/PCDF are semi-volatile organic compounds with high boiling points and can exist in the gas or solid phase depending on the flue gas temperature. Several studies have shown that PCDD is destroyed at temperatures above 800°C. However, without proper mixing or sufficient residence time, all PCDD/PCDF may not be destroyed even at these high temperatures.

If the PCDD/PCDF are in particulate form, an efficient particulate control device is needed to control these emissions to low levels. Table 1-2 summarizes the control device and control device efficiency for the Tier 4 tests. Based on the table and other data presented in Chapters 5 and 6, the following observations can be made:

- Three combustion devices tested during Tier 4 were equipped with afterburners operating at temperatures above the reported

TABLE 1-2. AVERAGE EMISSION CONTROL EFFICIENCIES AND INLET CONCENTRATIONS FOR TOTAL PCDD AND TOTAL PCDF

Control Device/ Test Site	Total PCDD Inlet Concentration (ng/dscm @ 3% O_2)	Total PCDD Average Measured Efficiency (Percent)	Total PCDF Inlet Concentration (ng/dscm @ 3% O_2)	Total PCDF Average Measured Efficiency (Percent)
Electrostatic Precipitators				
BLB-A	1.8	46	1.5	58
BLB-B	17.1	(23)	1.1	(-101)
BLB-C	9.0	62	15.1	40
Baghouse				
WFB-A	102	-130	154	39
Spray Dryer/Baghouse				
CRF-A	28.8	88	70.1	95
Water Scrubber				
SSI-A	101	40	455	(-19)
Afterburner				
DBR-A	687	99	2,170	99

Note: Values in parentheses ( ) indicate averages calculated from positive and negative values.

destruction temperature for PCDD (i.e., $800^{o}C$ or $1,470^{o}F$) and were emitting PCDD's. This finding indicates that, in addition to temperature, other factors such as residence time and mixing must be accounted for when controlling CDD's.

- Results for one of the tested afterburners on a drum and barrel reclamation furnace showed a control device efficiency greater than 98 percent for reducing PCDD emissions. Control device efficiency was not measured for the other combustion devices using afterburners because inlet MM5 sampling was not performed at these sites.
- A spray dryer/fabric filter combination installed on a carbon regeneration furnace was more effective at PCDD control than a fabric filter alone installed on a wood-fired boiler. This indicates that perhaps cooling/nucleation/condensation effects are needed to effectively control PCDD. Alternatively, this may imply that removal of reactive species such as HCl prior to particulate control is needed to improve PCDD/PCDF removal efficiency.
- Fabric filters, which are generally considered to be effective particulate control devices, appear to be ineffective PCDD/PCDF emission control devices when used alone.

A statistical analysis was also performed using the data obtained during the Tier 4 testing. The purpose of the analysis was to determine if PCDD, PCDF, and 2378-TCDD emissions were related to source type, combustion conditions, feed type and other factors. Non-parametric rank order statistical techniques were used since the data were not well distributed across all possible values of the variables. Rank order plots of the dependent variables (i.e., 2378-TCDD, total PCDD and total PCDF emissions) versus the independent variables (source type, feed total organic chloride, feed chlorine, feed precursors, combustion temperature, etc.) were developed. The degree of association between paired variables was tested using the Spearman Rank Correlation Coefficient. The analysis yielded the following results:

- Using all available data, there seems to be a strong association between total PCDD and 2378-TCDD emissions ($R = 0.93$). There is also a strong association between total PCDD and total PCDF emissions (R = 0.86).

- There is a moderate association between total HCl emissions and outlet PCDD emissions in the Tier 4 data set (R = 0.73), if the data from one site (MET-A) are excluded. However, this correlation does not hold for the inlet emissions data.
- Using Tier 4 control device inlet data there is a potential strong inverse association between maximum temperature and inlet total PCDD/PCDF levels (R = -0.85). An inverse association was also seen between the rankings of combustion temperature and PCDD emissions for the municipal solid waste combustor data set. A weaker inverse association was also found for the PCDF emissions data.
- Using the maximum of outlet or inlet data from the Tier 4 test sites, rank correlation shows a moderate association between total organic halide (TOX) content of the feed and both maximum PCDD and maximum PCDF emissions (R = 0.81).

A more complete discussion of the results of the engineering analysis is contained in Chapter 6 of this report.

A comprehensive quality assurance program was implemented for the Tier 4 sampling effort. The program emphasized 1) adherence to prescribed sampling procedures, 2) careful documentation of sample collection and field analytical data, 3) use of chain-of-custody records, 4) adherence to prescribed analytical procedures, and 5) implementation of independent systems and performance audits. Overall, the quality assurance program was successful, in that data were generally controlled within acceptable limits and sufficient data were provided to assess the uncertainty in the results. A more complete description of the quality assurance program for Tier 4 is in Chapter 7 of this report.

Ash sampling was conducted under the Tier 4 study as a complimentary effort to the more expensive stack sampling. While it was recognized that stack sampling was the rigorous means to determine CDD and CDF emissions from combustion sources, ash sampling was believed to be a useful indicator of stack emissions. Therefore, a larger number of combustion source categories were evaluated using ash sampling.

Chapter 8 of this report presents ash data from 75 separate combustion sources representing twenty-two different source categories. The types of ash sampled included baghouse ash, multicyclone ash, electrostatic precipitator ash, afterburner ash, settling chamber ash, bottom ash, economizer ash, and particulates filtered from scrubber water. CDD's and CDF's were found in about one-third of the bottom ash and fly ash samples and about one-half of the scrubber effluent samples. The highest concentrations were typically found in fly ash samples. Twelve of the twenty-two source categories had one or more ash samples with detectable concentrations. Combustion conditions were also recorded when the samples were collected. Chapter 8 discusses the effects of combustion parameters on CDD/CDF in the ash.

A subset of the ash data base involves sources where both ash samples and stack samples were collected simultaneously. This subset covers ten combustion sources generally consisting of three samples of both ash and stack samples. Chapter 8 presents an analysis of the ash data vs. the stack data. In general, it was observed that the presence of CDD's and CDF's in the fly ash appears to be a useful indicator of the presence of CDD's and CDF's in the stack emissions. When PCDD/PCDF homologues were measured in the stack gas, they were also detected in the control device ash indicating that control device ash has potential use as a screening tool. However, no quantitative relationship was observed that could reliably predict the magnitude of CDD/CDF emissions in the stack gases.

CHAPTER 2
BACKGROUND

This chapter presents background information on the Tier 4 Program and is organized as follows: Section 2.1 gives an overview of the purpose and organization of the National Dioxin Study. Section 2.2 outlines Tier 4 and the steps taken to fulfill the directives of the National Dioxin Strategy for Tier 4. Background information on CDD's and CDF's, as well as definitions of the nomenclature used in this report, follow in Section 2.3.

2.1 THE NATIONAL DIOXIN STRATEGY

2.1.1 Purpose of the National Dioxin Strategy

On December 15, 1983, EPA released a National Dioxin Strategy which provided a framework under which EPA was to:

1. Study the nature and extent of environmental contamination of 2378-TCDD and the associated risks to humans and the environment;
2. Implement or compel necessary clean-up actions at contaminated sites; and
3. Further evaluate regulatory alternatives to prevent future contamination, as well as disposal alternatives to alleviate current problems.

To implement the strategy, EPA formed seven study tiers, ordered by the decreasing potential for 2378-TCDD contamination:

Tier 1 - 2,4,5-trichlorophenol (245-TCP) production sites and associated waste disposal sites;

Tier 2 - Sites (and associated waste disposal sites) where 245-TCP was used as a precursor to make pesticide products;

Tier 3 - Sites (and associated waste disposal sites) where 245-TCP and its derivatives were formulated into pesticidal products;

Tier 4 - Combustion sources;

Tier 5 - Sites where pesticides derived from 245-TCP have been and are being used on a commercial basis;

Tier 6 - Certain organic chemical and pesticide manufacturing facilities where improper quality control on certain production processes could have resulted in the formation of a 2378-TCDD contaminated product waste stream; and

Tier 7 - Control sites where contamination from 2378-TCDD is not suspected.

2.1.2 Management of the National Dioxin Strategy

Overall management responsibility for the National Dioxin Strategy was assigned to the Assistant Administrator for the Office of Solid Waste and Emergency Response (OSWER). OSWER also managed the investigations for Tier 1 and Tier 2 of the study. The Office of Water Regulations and Standards (OWRS) managed Tiers 3, 5, 6 and 7, while the Office of Air and Radiation (OAR) oversaw Tier 4. The Office of Research and Development (ORD) was responsible for overall sampling and analytical guidance. ORD also provided analytical support for Tiers 3 through 7 through two of three EPA laboratories collectively known as Troika. The EPA laboratory at Bay St. Louis performed all of the extractions for the Tier 4 samples, and PCDD/PCDF analyses were performed at EMSL, Research Triangle Park. EPA's Regional Offices were responsible for implementing various aspects of the National Dioxin Strategy, including portions of Tier 4. A Tier 4 Work Group composed of representatives from throughout the Agency functioned in an advisory role in the formulation of plans and in the review of the results.

2.1.3 Tier 4: Combustion Sources

The National Dioxin Strategy directed Tier 4 to focus on "combustion sources, such as incineration of hazardous and municipal waste (including sewage sludge), wire reclamation facilities, internal combustion engines, home heating units (i.e., wood burning stoves), industrial fossil fuel-fired boilers, and inadvertent combustion sources." This broad directive covered literally millions of individual sources. Since it would have been economically and otherwise impractical to test each source or even each source category, considerable thought and judgment went into planning how best to answer the following questions:

1. Which, if any, combustion source categories are likely to emit 2378-TCDD and other chlorinated isomers of CDD's and CDF's?
2. At what concentrations are these compounds emitted to the environment?
3. Do the ambient air concentrations resulting from emissions of these compounds pose an unreasonable risk to the public?

The results from Tier 4 have been summarized in a report to Congress. The results will provide data necessary to help make a decision on whether to list "dioxin" as a hazardous air pollutant under Section 112 of the Clean Air Act.

2.2 TIER 4 OVERVIEW

The Air Management Technology Branch (AMTB) within the EPA's Office of Air Quality Planning and Standards (OAQPS) in conjunction with the Hazardous Waste Environmental Research Laboratory, Cincinnati, was responsible for the development and implementation of the source testing program for Tier 4 of the National Dioxin Study.

The Tier 4 Project began in November 1983. The project was performed in a series of interrelated and overlapping steps. These were as follows:

1. Perform an initial literature review; collect and review available literature on combustion related emission sources of PCDD's and PCDF's. Develop a source test-plan based on the available CDD/CDF emissions data. Adopt a "state-of-the-art" test method.
2. Develop a project plan incorporating the initial literature review findings.
3. Solicit regional and State inputs for potential source test sites and prepare ash sampling, source sampling, and quality assurance plans for the source sampling efforts.
4. Implement the source test plans and the ash sampling plans.
5. Collect and analyze all the data generated; prepare Engineering Analysis and Project Summary reports.

Twenty-one EPA documents, including this report, have been produced as a result of the above-mentioned steps. These are as follows:

National Dioxin Study Tier 4 - Combustion Sources

- Project Plan - EPA-450/4-84-014a
- Initial Literature Review and Testing Options - EPA-450/4-84-014b
- Sampling Procedures - EPA-450/4-84-014c
- Ash Sampling Program - EPA-450/4-84-014d
- Quality Assurance Project Plan - EPA-450/4-84-014e
- Quality Assurance Evaluation - EPA-450/4-84-014f
- Engineering Analysis Report - EPA-450/4-84-014h
- Final Literature Review - EPA-450/4-84-014i
- Final Test Report - Site 1, Sewage Sludge Incinerator SSI-A EPA-450/4-84-014j
- Final Test Report - Site 2, Industrial Solid Waste Incinerator ISW-A - EPA-450/4-84-014k
- Final Test Report - Site 3, Sewage Sludge Incinerator SSI-B - EPA-450/4-84-014l
- Final Test Report - Site 4, Black Liquor Boiler BLB-A - EPA-450/4-84-014m
- Final Test Report - Site 5, Black Liquor Boiler BLB-B - EPA-450/4-84-014n
- Final Test Report - Site 6, Wire Reclamation Incinerator WRI-A - EPA-450/4-84-014o
- Final Test Report - Site 7, Wood-Fired Boiler WFB-A - EPA-450/4-84-014p
- Final Test Report - Site 8, Black Liquor Boiler BLB-C - EPA-450/4-84-014q
- Final Test Report - Site 9, Carbon Regeneration Furnace CRF-A - EPA-450/4-84-014r
- Final Test Report - Site 10, Secondary Copper Recovery Cupola Furnace MET-A - EPA-450/4-84-014s
- Final Test Report - Site 11, Drum and Barrel Reclamation Furnace DBR-A - EPA-450/4-84-014t

- Final Test Report - Site 12, Sewage Sludge Incinerator SSI-C - EPA-450/4-84-014u
- Final Test Report - Site 13, Residential Woodstove WS-A - EPA-450/4-84-014v

Radian Corporation, under task order contract, provided support to AMTB and Tier 4 in the following areas:

1. Development of a project plan for Tier 4.
2. Collection and review of available literature data on combustion-related sources of PCDD and PCDF emissions.
3. Development of a source test plan.
4. Preparation of a sampling procedures document.
5. Development of a QA plan for the sampling effort.
6. Emissions testing at 13 combustion facilities.
7. Implementation of an ash sampling program.
8. Preparation of source test and other reports.

The purposes of this report are to summarize all of the data gathered during the Tier 4 study and to analyze the data. The analysis addresses the following questions:

1. Which combustion source categories emit chlorinated dibenzo-p-dioxins and dibenzofurans to the atmosphere?
2. What range of concentrations of chlorinated dibenzo-p-dioxins and dibenzofurans are emitted from these source categories?
3. What factors affect emissions of chlorinated dibenzo-p-dioxins and dibenzofurans from combustion sources?
4. How does the distribution of the tetra through octa chlorinated CDD and CDF homologues vary between combustion sources?
5. How effective are conventional emission control devices in reducing chlorinated CDD and CDF emissions from combustion sources?

2.3 BACKGROUND INFORMATION ON CHLORINATED DIBENZO-p-DIOXINS AND CHLORINATED DIBENZOFURANS

2.3.1 Structure

Compounds which are generally labeled by the public as "dioxins" are members of a family of organic compounds known chemically as dibenzo-p-dioxins. The common aspect of all dibenzo-p-dioxin compounds is that they have a three ring nucleus consisting of two benzene rings interconnected by a pair of oxygen atoms. The structural formula of the dioxin nucleus and the convention used in numbering its substituent positions are shown in Figure 2-1a. In general, the term "dioxins" is used to mean the chlorinated isomers of dibenzo-p-dioxin. One to eight chlorine atoms can occur at dioxin substituent positions such that 75 chlorinated dioxin isomers are possible. Each isomer has its own physical and chemical properties and differs from others in the number and relative position of its chlorine atoms. The potential chlorinated dioxin isomers are listed in Table 2-1.

One of the 22 isomers with four chlorine atoms is 2,3,7,8-tetrachlorodibenzo-p-dioxin (2378-TCDD). This isomer is the principal focus of the Tier 4 study for three reasons:

1. 2378-TCDD is believed to be the most toxic of the chlorinated dioxins,
2. 2378-TCDD is the isomer most often associated with exposure and potential health risks to humans, and
3. sufficient associated health and exposure information is available on 2378-TCDD to allow a targeted study to be developed.

The compounds generally referred to as "furans" are members of a family of organic compounds known chemically as dibenzofurans. They have a similar structure to the dibenzo-p-dioxins except that the two benzene rings in the nucleus are interconnected with a five member ring containing only one oxygen atom. The structural formula of the furan nucleus and the convention used in numbering its substituent positions are shown in Figure 2-1b. The chlorinated furan group can contain up to 135 different structural isomers, each with varying physical and chemical properties. The potential chlorinated furan isomers are listed in Table 2-2.

2.3.2 Nomenclature Used in This Report

Throughout this document the terms CDD and CDF will be used to generically indicate chlorinated dibenzo-p-dioxin or dibenzofuran compounds as distinguished from specific chlorinated CDD or CDF isomers. The abbreviations PCDD and PCDF are used to indicate polychlorinated dibenzo-p-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF) with four or more chlorine atoms. In

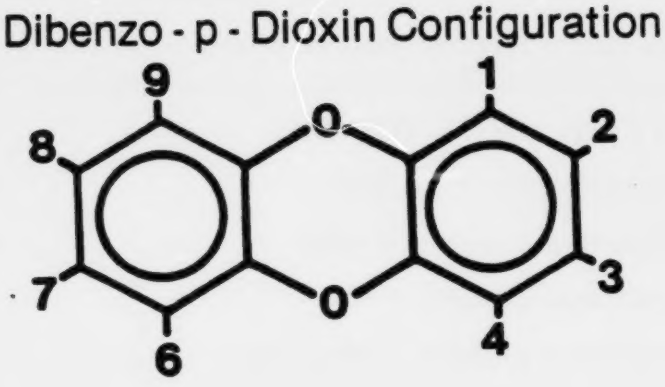
Dibenzo - p - Dioxin Configuration
9
1
8
2
O
7
3
O
6
4

Figure 2-1a. Structural Formula of the Dioxin Nucleus

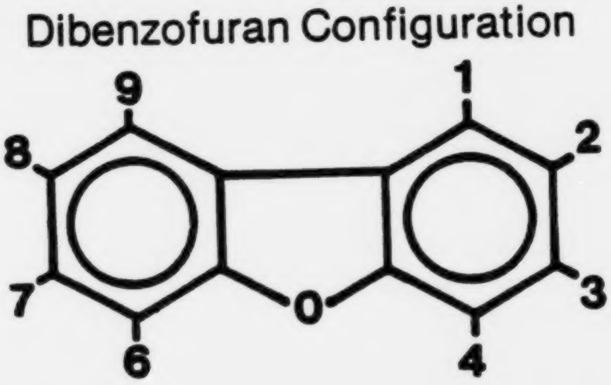
Dibenzofuran Configuration
9
1
8
2
7
3
O
6
4

Figure 2-1b. Structural Formula of the Furan Nucleus

Table 2-1. Nomenclature and Schedule of Theoretical Chlorinated Dioxin Isomers

Chlorinated Dioxin Compound (abbreviation)	No. of Isomers
Monochlorodibenzo-p-dioxin (Mono-CDD)	2
Dichlorodibenzo-p-dioxin (Di-CDD)	10
Trichlorodibenzo-p-dioxin (Tri-CDD)	14
Tetrachlorodibenzo-p-dioxin (TCDD)	22
Pentachlorodibenzo-p-dioxin (Penta-CDD)	14
Hexachlorodibenzo-p-dioxin (Hexa-CDD)	10
Heptachlorodibenzo-p-dioxin (Hepta-CDD)	2
Octachlorodibenzo-p-dioxin (Octa-CDD)	1
TOTAL ISOMERS	75

the discussion of emissions data the terms total PCDD and total PCDF represent the sum of the emissions of the tetra through octa homologues. The term "chlorinated CDD/CDF homologue" will be used to indicate the family of CDD/CDF isomers with a fixed number of chlorine atoms. For example, the tetra chlorinated CDD homologue consists of all CDD isomers containing four chlorine atoms. The abbreviations used for chlorinated CDD/CDF homologues are included in Tables 2-1 and 2-2.

2.3.3 Report Organization

The remainder of this report is organized as follows: Chapter 3 presents a summary of the literature survey, and the development of the source test plan is outlined in Chapter 4. The results of the emissions test program are presented in Chapter 5, and an analysis of the emissions test program data is summarized in Chapter 6. The Quality Assurance Program for Tier 4 is described in Chapter 7, and the Ash Sampling Program is described in Chapter 8.

Table 2-2. Nomenclature and Schedule of Theoretical Chlorinated Furan Isomers

Chlorinated Furan Compound (abbreviation)	No. of Isomers
Monochlorodibenzofuran (Mono-CDF)	4
Dichlorodibenzofuran (Di-CDF)	16
Trichlorodibenzofuran (Tri-CDF)	28
Tetrachlorodibenzofuran (TCDF)	38
Pentachlorodibenzofuran (Penta-CDF)	28
Hexachlorodibenzofuran (Hexa-CDF)	16
Heptachlorodibenzofuran (Hepta-CDF)	4
Octachlorodibenzofuran (Octa-CDF)	1
TOTAL ISOMERS	135

CHAPTER 3
LITERATURE REVIEW

A literature review for sources of PCDD and PCDF air emissions was made in 1983 by the Pollutant Assessment Branch (OAQPS/PAB) of the United States Environmental Protection Agency (EPA).[A] This review was used as a starting point for a more focused literature search concerning PCDD emissions from combustion sources in early 1984. The 1984 literature review identified sources of PCDD and PCDF air emissions and provided the data base on which the Tier 4 testing program was developed.[B] At the conclusion of the source testing efforts, a final update of this review was conducted to include CDD/CDF emissions information available through July of 1985.

This chapter summarizes the final literature review. Industrial, commercial, and residential combustion sources that have been tested for CDD/CDF emissions are identified. Quantitative data are presented on emissions of 2378-TCDD, PCDD's, and PCDF's. Qualitative information on the source characteristics, feed composition, and sampling and analytical methodologies are also presented.

Sections 3.1 and 3.2 present a summary of the literature review. Emissions data are presented for 2378-TCDD, PCDD, and PCDF, along with qualitative information on source characteristics. CDD/CDF formation hypotheses are summarized in Section 3.3. Section 3.4 presents a discussion of factors affecting CDD emissions.

[A] Brooks, G. W. Summary of a Literature Search to Develop Information on Sources of Chlorinated Dioxin and Furan Air Emissions. Final Report. Contract No. 68-02-3513. U. S. Environmental Protection Agency, October 1983.

[B] (Radian Corporation) National Dioxin Study--Tier 4 Combustion Sources. Initial Literature Review and Testing Options. EPA-450/4-84-014B. October 1984.

3.1 OVERVIEW OF THE LITERATURE DATA BASE

A review of the literature identified thirteen broadly defined source categories for which some PCDD and PCDF emissions data have been collected:

- municipal solid waste incinerators,
- sewage sludge incinerators,
- fossil fuel combustion,
- wood combustion,
- boilers co-firing wastes,
- hazardous waste incinerators,
- hospital incinerators,
- lime/cement kilns,
- wire reclamation incinerators,
- PCB fires,
- automobile emissions,
- activated carbon regeneration furnaces, and
- experimental studies.

The PCDD and PCDF emissions data for each source category are presented in the following sections. The primary purposes of this presentation are to identify combustion sources that emit PCDD's and PCDF's and, as a result of comparisons of emissions and source characteristics, to identify combustion sources that are unlikely to emit PCDD's and PCDF's. A positive finding in the literature (i.e., detectable CDD emissions) may suggest the tested combustion source emits CDD, but this conclusion can only be reached after consideration of the quality of the reported data or research. Likewise, a negative finding in the literature (i.e., less than detectable CDD emissions) may be misleading if high detection limits or inappropriate sampling and analysis methods were used. Direct comparison of data reported in the literature by various researchers is difficult and should be done with caution for several reasons. The data are often reported on different bases which cannot easily be interconverted because of the lack of source-specific information. A variety of sampling and analytical procedures were often used, and detection limits are frequently not specified. Facility design and operation may vary considerably and this type of information is often incompletely reported. Also, some data are available from draft reports, emission tests, and other unpublished documents which have not been subjected to peer or editorial review. In this chapter, all available literature data were summarized. No attempt was made to exclude any reference because of the quality of the data. For this reason, analysis or full explanation of the literature data is not possible. However, for the purpose of the Tier 4 Study, broad generalizations can be made. Elsewhere in this document where literature data are used quantitatively, only data of verifiable high quality were used.

In the following sections, emission test results are presented separately for each study along with appropriate tables. If available, information is provided in the text about the combustion unit, analysis of feed samples, or identification of precursors present in the feed materials. When available, detection limits are specified. If analytical methods other than gas chromatography-mass spectrometry (GC-MS) were used, that information is noted in the text.

3.1.1 Summary of Stack PCDD and PCDF Emissions

Table 3-1 presents a summary of stack PCDD and PCDF emissions data available from the literature for combustion sources. The data for each source category are discussed in detail in Section 3.2. For each source category the total number of facilities tested is shown, as is the type of sample. The ranges of detected emissions and detection limits are shown for the 2378-TCDD isomer, PCDD's, and PCDF's. The column labeled "Detected Range" represents the range of average concentrations reported by the various literature references. If only one value is shown it represents the average value of all tests for one unit. The number of sources having detectable emissions is shown in parentheses under the range values. Detection limits are shown in the column labeled "Detection Limits" when a source had less than detectable PCDD or PCDF emissions. The number of sources having less than detectable emissions is shown in parentheses under the detection limits. Comments are provided if the results were affected by such things as contaminated fuel, upset operating conditions, or use of a nonspecific analytical technique. In the table, the source categories are ordered by the highest value of the PCDD emissions range.

TABLE 3-1. SUMMARY OF PCDD/PCDF STACK EMISSIONS DATA FROM THE LITERATURE^{a,b,c,d}

Source Category [Total # Tested]	Sample Type	2378 TCDD (ng/m^3) Detected Range	2378 TCDD (ng/m^3) Detection Limits	PCDD (ng/m^3) Detected Range	PCDD (ng/m^3) Detection Limits	PCDF (ng/m^3) Detected Range	PCDF (ng/m^3) Detection Limits	Reference/Comments
Municipal Waste Incinerators								
o European [8]	FG^e	-	-	71-48,997 (8)	-	37-9,831 (8)	-	43, 87, 109
o U.S. and Canada [9]	FG	0.2-95 (6)	-	3.3-11,686 (9)	-	8.5-22,000 (9)	-	32, 49, 92, 101, 168, 174, 181, 196, 205
Boilers Cofiring Wastes								
o Commercial [3]	FG	-	-	1,400-17,000 (3)	NA^f (3)	170 (1)	NA (2)	81: o Boilers cofiring spiked waste oil. o PCDD refers to only TCDD and OCDD in this reference.
o Industrial [5]	FG	0.002 (1)	<0.002-1.5 (1)	0.64-76.4 (5)	<0.002-1,000 (4)	0.15-5.5 (3)	<0.002-1,000 (4)	40, 41: o Highest PCDD levels from 2 boilers firing creosote sludge. Creosote sludge feed for 1 boiler was contaminated with PCDD's.
o Utility [1]	FG	ND	<0.031-0.10 (1)	ND	<0.031-0.10 (1)	ND	<0.031-0.10 (1)	96: o PCB-spiked waste oil feed.
Wood Combustion								
o PCP-Treated Wood [2]	FG	-	-	1,520 (1)	<17ppb (1)	587 (1)	<17ppb (1)	220, 233: o The one unit with less than detectable emissions was designed to incinerate PCP-treated wood; the other unit was not. o Detection limits reported in terms of v/v.

(Continued)

TABLE 3-1. SUMMARY OF PCDD/PCDF STACK EMISSIONS DATA FROM THE LITERATURE^{a,b,c} (Continued)

Source Category [Total # Tested]	Sample Type	2378 TCDD (ng/m^3) Detected Range	2378 TCDD (ng/m^3) Detection Limits	PCDD (ng/m^3) Detected Range	PCDD (ng/m^3) Detection Limits	PCDF (ng/m^3) Detected Range	PCDF (ng/m^3) Detection Limits	Reference/Comments
Sewage Sludge Incinerators [2]	FG	-	-	812 (1)	NA (1)	1,374 (1)	NA (1)	24, 235: o In Ref. 235, results reported as "dioxins" and "furans" assumed to be PCDD/PCDF. o In Ref. 24, "fumes" were trapped with water condenser.
Hospital Incinerators [4]	FG	-	-	15-69 (4)	-	25-156 (4)	-	31a, 62a
Hazardous Waste Incinerators								
o Rotary Kiln [2]	FG	-	-	20.3-36.6 (2)	-	11.2-93.8 (2)	-	88, 153a: o Fuels were PCB's (88) and chlorophenolic wastes (153a).
Activated Carbon Regeneration								
o w/o Afterburner [1]	FG	0.1 (1)	-	0.18 (1)	-	0.3 (1)	-	13: o Fluidized bed combustion before installation of afterburner.
o w/ Afterburner [1]	FG	-	-	1.58 (1)	-	0.05 (1)	-	156: o Fluidized bed combustion after installation of afterburner. o PCDD means only H7CDD and OCDD homologs. o PCDF means only H6CDF, H7CDF, OCDF homologs.

(Continued)

TABLE 3-1. SUMMARY OF PCDD/PCDF STACK EMISSIONS DATA FROM THE LITERATURE[a,b,c] (Continued)

Source Category [Total # Tested]	Sample Type	2378 TCDD (ng/m^3) Detected Range	2378 TCDD (ng/m^3) Detection Limits	PCDD (ng/m^3) Detected Range	PCDD (ng/m^3) Detection Limits	PCDF (ng/m^3) Detected Range	PCDF (ng/m^3) Detection Limits	Reference/Comments
Cement Kilns [3]	FG	-	-	1.35 (1)	<1 ng/ul (2)	0.74 (1)	<1 ng/ul (2)	20a, 20b, 184: o In one of four SASS trains, H7CDD and H7CDF homologs detected only (Ref. 184). o Detectable emissions occurred during upset combustion conditions. o Detection limits expressed in terms of ng/ul injected into GC-MS.
Lime Kilns [1]	FG	-	-	ND	<0.34-2.0 (1)	-	-	58a
Fossil Fuel Boilers								
o Coal-fired Utility [4]	FG	-	-	ND	<0.10-0.70 (4)	-	<0.10-0.70 (4)	94
o Pulverized Coal [1]	FG	ND	<4.2-7.9 (1)	-	-	-	<0.67-1.3 (1)	5: o 2378 TCDD/F scan only.
o Oil-fired Utility [1]	FG	ND	<4.2-7.9 (1)	-	-	-	<0.67-1.3 (1)	5: o 2378 TCDD/F scan only.

(Continued)

TABLE 3-1. SUMMARY OF PCDD/PCDF STACK EMISSIONS DATA FROM THE LITERATURE[a,b,c] (Continued)

Source Category [Total # Tested]	Sample Type	2378 TCDD (ng/m^3)		PCDD (ng/m^3)		PCDF (ng/m^3)		Reference/Comments
		Detected Range	Detection Limits	Detected Range	Detection Limits	Detected Range	Detection Limits	
Incinerator Ships								
o M/T Vulcanus [1]	FG	-	-	ND	<0.0009-0.086 ng/ml (1)	-	-	1: o TCDD scan only. o Fuel was Herbicide Orange. o Detection limits expressed in terms of ng/ml injected into GC-MS.
o M/T Vulcanus [1]	FG	ND	NA (1)	ND	NA (1)	-	<0.3-3 (1)	2: o TCDD/TCDF scans only. o Feed samples were contaminated with PCDF's. o Feed was PCB's.

"—" means no data were available because analysis was not done or data were not reported.

[a] Detected Range is range of average levels detected. If only one value is shown it represents the average value of all tests for one unit. The number of sources having detectable emissions is shown in parentheses under the range values.

[b] Detection limits are shown when a source had less than detectable emissions. The number of sources having less than detectable emissions is shown in parentheses under the detection limits.

[c] The number in parentheses below each range represents the number of units having detectable or less than detectable emissions.

[d] ND = Not Detected

[e] FG = Flue Gas

[f] NA = Not Available

Reported PCDD/PCDF concentrations are reported "as-measured."

PCDD's and PCDF's were not found in stack emissions from all combustion sources. Utility boilers firing PCB-spiked waste oil, a lime kiln, a coal-fired utility boiler, and the incinerator ship M/T Vulcanus had less than detectable PCDD and (if analyzed for) PCDF emissions.

In general, where combustion sources did emit PCDD's or PCDF's, these emissions appeared to be dependent on the types of fuel or wastes being fired, and whether or not the combustion unit was designed and operated specifically to achieve the destruction of potentially hazardous wastes including PCDD's and PCDF's. However, sampling and analysis methods and facility design and operation may vary considerably between studies, which makes direct comparisons of emissions test data difficult. For most of the sources tested, the magnitude of PCDD emissions was comparable to the magnitude of PCDF emissions. Most of the studies analyzed samples for PCDD's; some studies quantitated 2378-TCDD and the PCDF homologues as well. Samples were taken primarily at the stack outlet location and not at the control device inlet. The range of measured PCDD and PCDF concentrations varied from one to four orders of magnitude.

Based on the Tier 4 literature review, two municipal solid waste incinerators were the most frequently tested source and had the highest levels of PCDD's and PCDF's in stack gas emissions. Facilities located in Europe had higher PCDD emissions than North American facilities. Commercial boilers co-firing spiked waste oil had the next highest PCDD concentration in stack gas emissions, followed by emissions from one tested unit combusting PCP-treated wood. However, another combustion unit designed to incinerate PCP-treated wood had less than detectable PCDD or PCDF emissions. Of the remaining source categories tested, sewage sludge incinerators, hospital incinerators, and two rotary kiln hazardous waste incinerators had the next highest PCDD emissions, respectively.

Emissions data for the 2378-TCDD isomer were available for five source categories. Municipal waste incinerators had the highest stack emissions of 2378-TCDD, followed by a fluidized bed system used to regenerate activated carbon, and an industrial boiler. One coal-fired utility boiler and the incinerator ship M/T Vulcanus had nondetectable levels of the 2378-TCDD isomer.

3.1.2 Summary of PCDD and PCDF in Ash Emissions

Table 3-2 presents a summary of data on the PCDD and PCDF content of combustion ash samples available in the literature. The data for each source category are discussed in detail in Section 3.2. As in Table 3-1, Table 3-2 shows the number of facilities tested and the type of sample. The range of detected emissions and detection limits for the 2378-TCDD isomer, PCDD's and PCDF's are also shown for each source category. The source categories are ordered by the highest value of the PCDD range for each category.

PCDD's and PCDF's were not found in ash samples from all combustion sources. Three rotary kilns, thirteen coal-fired boilers, two diesel cars, a lime kiln, and a sewage sludge incinerator had less than detectable levels of PCDD's or PCDF's (if analyzed for) in ash or particulate samples.

A rotary kiln operated without supplemental fuel fired in the afterburner had the highest PCDD concentration in particulate samples. However, according to the author these results were skewed high by the use of a nonspecific GC-MS packed column analytical method. The same rotary kiln operated with supplemental fuel had significantly lower PCDD levels in particulate samples. PCB fires had the second highest PCDD concentration in soot samples, and also had the highest PCDF levels. Unlike flue gas samples, the level of PCDD's found in ash samples were less than PCDF levels for most of the combustion sources where both PCDD's and PCDF's were analyzed for. Municipal waste incinerators had the next highest concentrations of PCDD's in ash samples. In general, European facilities had higher levels of PCDD's than North American or Japanese facilities. However, two European facilities had less than detectable PCDD's in ash samples. North American facilities had higher PCDF levels in ash samples than European facilities. A natural gas-fired residential heater had the next highest PCDD levels in particulate material, followed by a commercial boiler co-firing used automobile oil spiked with organic compounds, and a hospital incinerator. Residential woodstoves had detectable levels of PCDD's in ash samples, but some of the fuel was reported to have been potentially contaminated. Other source

TABLE 3-2. SUMMARY OF LITERATURE DATA ON PCDD AND PCDF CONTENTS OF COMBUSTION ASH[a,b,c]

Source Category [Total # Tested]	Sample Type	2378 TCDD (ng/g) Detected Range	2378 TCDD (ng/g) Detection Limits	PCDD (ng/g) Detected Range	PCDD (ng/g) Detection Limits	PCDF (ng/g) Detected Range	PCDF (ng/g) Detection Limits	Reference/Comments
Hazardous Waste Incinerators								
o Rotary Kiln [1] w/o Supplemental Fuel	Part.	1,870 (1)	-	323,570 (1)	-	-	-	62: o Results skewed high by nonspecific analytical method used for one of three test runs. o No supplemental fuel fired in afterburner.
o Rotary Kiln [1] w/Supplemental Fuel	Part	ND[d]	<2-5 (1)	267 (1)	-	-	-	62: o Supplemental fuel fired in afterburner.
o Tar Burner [1]	Part.	ND	<1.3-3 (1)	406 (1)	-	-	-	62
o Mobile Incinerator [1]	Ash	-	-	91.3 ng (1)	-	-	-	108: o OCDD homolog only, suspected contaminant. Leakage of samples prevented concentration calculation.
o Rotary Kiln [3]	Part.	-	-	ND	NA[e] (3)	ND	NA (2)	161

(Continued)

TABLE 3-2. SUMMARY OF LITERATURE DATA ON PCDD AND PCDF CONTENTS OF COMBUSTION ASH^{a,b,c} (Continued)

Source Category [Total # Tested]	Sample Type	2378 TCDD (ng/g) Detected Range	2378 TCDD (ng/g) Detection Limits	PCDD (ng/g) Detected Range	PCDD (ng/g) Detection Limits	PCDF (ng/g) Detected Range	PCDF (ng/g) Detection Limits	Reference/Comments
PCB Transformer Fires [8]	Soot	59-600 (2)	-	324-19,400 (2)	<10-100 (2)	1,710-2,160,000 (4)	-	60, 99, 150: o 2 transformer fires with high PCDF levels had less than detectable levels of PCDD.
	Wipes	-	-	-	-	772-10,900 ng/m^2 (2)	-	76, 192: o Results reported in terms of surface area.
	Liquid	-	-	-	-	75,000 (1)	-	110: o Liquid from inside exploded capacitor.
	Ash	-	-	5.2 (1)	-	41.4 (1)	-	218: o Only H7CDD and OCDD homologs detected.
Municipal Waste Incinerator								
o European [32]	FA	-	-	0.2-3537 (29)	NA (2)	1.93-1,770 (17)	-	12, 25, 26, 33, 43, 71, 116, 118, 143, 144, 178
o U.S. and Canada [21]	FA	5.2 (1)	-	6.2-2,300 (14)	-	10-3,100 (12)	-	47, 49, 69, 70, 71, 90, 92, 168, 181, 203, 222
o Japanese [2]	FA	-	-	2.4-4.8 (2)	-	-	-	71

(Continued)

TABLE 3-2. SUMMARY OF LITERATURE DATA ON PCDD AND PCDF CONTENTS OF COMBUSTION ASH[a,b,c] (Continued)

Source Category [Total # Tested]	Sample Type	2378 TCDD (ng/g)		PCDD (ng/g)		PCDF (ng/g)		Reference/Comments
		Detected Range	Detection Limits	Detected Range	Detection Limits	Detected Range	Detection Limits	
Fossil Fuel Combustion								
o Natural Gas [1]	FA[f]	0.6 (1)	-	1,764 (1)	-	-	-	62: o H6CDD, H7CDD, and OCDD homologs only. Analyses by GC-EC.
o Coal and Oil [1]	Part.	-	-	68 (1)	-	-	-	62: o Feed may have had high chlorine content or contamination. o P5CDD not analyzed for.
o Coal [13]	FA	-	-	ND	<0.0006-0.07 (13)	ND	<0.01-0.07 (1)	59, 94, 97, 125
Boilers Co-firing Wastes								
o Commercial Boiler [1]	FA	-	-	911 (1)	-	3,777 (1)	-	81: o Co-firing used automobile oil spiked with organic compounds. o No TCDD's detected, only penta through octa homologs.
o Industrial Boiler [1]	FA	-	-	600 (1)	-	300 (1)	-	33: o Co-firing used industrial oils.
Hospital Incinerator [1]	FA	-	-	259 (1)	-	265 (1)	-	31a

(Continued)

TABLE 3-2. SUMMARY OF LITERATURE DATA ON PCDD AND PCDF CONTENTS OF COMBUSTION ASH^{a,b,c} (Continued)

Source Category [Total # Tested]	Sample Type	2378 TCDD (ng/g) Detected Range	2378 TCDD (ng/g) Detection Limits	PCDD (ng/g) Detected Range	PCDD (ng/g) Detection Limits	PCDF (ng/g) Detected Range	PCDF (ng/g) Detection Limits	Reference/Comments
Wood Combustion								
o Residential Woodstoves [24]	Ash	0.001-0.20 (15)	<0.0009- 0.0014 (2)	0.007-210 (24).	-	-	-	54, 62, 165, 167: o Some fuel may have been contaminated.
Activated Carbon Regeneration								
o w/o Afterburner [1]	Part.	25 (1)	-	48 (1)	-	103 (1)	-	13: o TCDD/TCDF scan only. o Fluidized bed combustion prior to installation of afterburner.
Automobile Emissions								
o Leaded gas [3]	Filter Extract	2.98 (3)	-	47.7 (3)	-	-	-	213: o One composite sample from 3 vehicles analyzed.
o Unleaded gas [10]	Filter Extract	1.4 (10)	-	37.4 (10)	-	-	-	213: o One composite sample from 10 vehicles analyzed.
o Diesel Truck [2]	Scraping	ND	<0.003 (2)	0.39-0.40 (2)	-	-	-	62
o Unleaded gas [2]	Scraping	ND	<0.0002 (2)	0.01-0.08 (2)	-	-	-	62
o Leaded gas [1]	Scraping	ND	<0.002 (1)	0.004 (1)	-	-	-	62
o Diesel Car [2]	Filter Extract	ND	<0.04 ng/sample (2)	ND	<0.04 ng/sample (2)	-	-	213 o TCDD scan only.

(Continued)

TABLE 3-2. SUMMARY OF LITERATURE DATA ON PCDD AND PCDF CONTENTS OF COMBUSTION[a,b,c] (Continued)

		2378 TCDD (ng/g)		PCDD (ng/g)		PCDF (ng/g)		
Source Category [Total # Tested]	Sample Type	Detected Range	Detection Limits	Detected Range	Detection Limits	Detected Range	Detection Limits	Reference/Comments
Wire Reclamation [1]	FA	-	-	0.41 (1)	-	11.6 (1)	-	103: o TCDD/TCDF scan only.
Cement Kiln [1]	Part.	-	-	-	-	44.8 (1)	-	184: o One of four Method 5 filters contained P5CDF, HCDF, and H7CDF. o Detectable emissions occurred during upset operating conditions.
Lime Kiln [1]	Baghouse dust	-	-	ND	<0.005-0.25 (1)	-	-	58a
Sewage Sludge Incineration								
	FA	-	-	ND	NA (1)	-	-	24: o Fly ash collected by dust abatement.
	Ashes	-	-	ND	NA (1)	-	-	24

"—" means no data were available because analysis was not done.

FA = Fly Ash; Part. = Particulate phase of gaseous sample; Filter Extract = Particulate Filter Extract; Scraping = Muffler Exhaust Scraping

[a] Detected range is range of average levels detected. If only one value is shown it represents the average value of all tests for one unit. The number of sources having detectable emissions is shown in parentheses under the range values.

[b] Detection limits are shown when a source had less than detectable emissions. The number of sources having less than detectable emissions is shown in parentheses under the detection limits.

[c] The number in parentheses is number of units having detectable or less than detectable emissions.

[d] ND = Not Detected

[e] NA - Not Available

[f] Particulate material

categories having detectable levels of PCDD's or PCDF's in particulate or ash samples were activated carbon regeneration, automobile emissions, wire reclamation, and a cement kiln.

Concentration data for the 2378-TCDD isomer were available for ash and soot taken from seven source categories. A rotary kiln burning tars, solid waste, and natural gas and operated without supplemental fuel being fired in the afterburner had the highest concentration of 2378-TCDD in particulate samples. However, the same rotary kiln had less than detectable emissions of 2378-TCDD when supplemental fuel (tars and natural gas) was fired in the afterburner. PCB fires had the second highest concentration of 2378-TCDD in soot samples followed by a fluidized bed combustion system used to regenerate activated carbon. Municipal waste incinerators had the next highest detectable levels of 2378-TCDD in fly ash samples, followed by filter extract samples from vehicles burning leaded and unleaded gasoline. Other sources having detectable levels of 2378-TCDD were a natural gas-fired residential heater and residential woodstoves. Particulate matter samples from a tar burner had less than detectable levels of 2378-TCDD.

3.2 EMISSIONS DATA FOR INDIVIDUAL SOURCE CATEGORIES

In this section, the available PCDD/PCDF emissions data for individual source categories are discussed. Sections 3.2.1 through 3.2.12 cover municipal solid waste incinerators, sewage sludge incinerators, fossil fuel combustion, wood combustion, boilers co-firing wastes, hazardous waste incinerators, lime/cement kilns, hospital incinerators, wire reclamation incinerators, PCB fires, automobile emissions, and activated carbon regeneration furnaces, respectively. Various experimental studies are discussed in Section 3.2.13.

3.2.1 Municipal Solid Waste Incinerators

Table 3-3 presents the emissions data for municipal solid waste incinerators. These data include information available in the literature through July of 1985. Subsequent to this report EPA has compiled information, including emissions data, for a number of municipal solid waste

TABLE 3-3. SOURCE CATEGORY: MUNICIPAL SOLID WASTE INCINERATORS

Type of Facility	No. of Units Tested (Location)	Sample	PCDD/PCDF Emission Concentration and Ash Sample Content[a] 2378-TCDD Mean	Range	PCDD Mean	Range	PCDF Mean	Range	References
MSW INCINERATORS:									
North America	9	FG	19.1 ng/m^3	0.2-95 ng/m^3	1,450 ng/m^3	ND-22,000 ng/m^3	2,436 ng/m^3	ND-15,060 ng/m^3	32, 49, 92, 101, 168, 174, 181, 196, 205
	21	FA	2.98 ppb	0.48-6.6 ppb	362.7 ppb	<0.5-2,300 ppb	923 ppb	<0.5-3,100 ppb	47, 49, 69, 70, 71, 90, 92, 168, 181, 203, 222
European	8	FG	-	-	2,935 ng/m^3	ND-48,997 ng/m^3	2,398 ng/m^3	37-7,460 ng/m^3	43, 87, 109
	31	FA	-	-	588 ppb	<0.5-3537 ppb	288 ppb	ND[b]-1,770 ppb	12, 25, 26, 33, 43, 71, 116, 118, 143, 144, 178
Japanese	2	FA	-	-	3.6 ppb	2.4-4.8 ppb	-	-	71

"—" means no data

FG = Flue Gas

FA = Fly Ash

[a] as-measured concentration

[b] ND = Not Detected. Assumed to be zero in calculations.

incinerators. These data will be presented in a forthcoming report entitled "Municipal Waste Combustion Study" (8 volumes).

In 1978, TCDD's were detected in the emissions from the Hempstead municipal waste incinerator (MWI) on Long Island. Since that date, this source category has received considerable attention in the United States. The Canadian Government has identified MWI's as one of the major combustion sources of PCDD's in the Canadian environment.[73] Numerous tests have also been conducted in Europe and Japan.

MWI's can be classified as either large mass burn units, refuse-derived fuel (RDF) units, or small modular units. There are approximately 43 facilities with modular units, 45 mass burn facilities and 8 RDF boiler facilities currently operating in the United States and Canada.[C] The mass burn facilities are responsible for the majority of waste burned.

The following subsections summarize the PCDD and PCDF flue gas emissions and fly ash content data for MWI's operating in North America (including Canada), Europe and Japan. The emissions data presented are based upon a review of the currently available literature that reports CDD and CDF emissions from MWI's. Thirty-eight articles were reviewed.

Emissions data are available for 62 MWI facilities. Fifty-seven are reported to use an electrostatic precipitator to control particulate matter emissions from flue gases. Twenty-six of the facilities are located in the United States and Canada, 34 in Europe, and 2 in Japan.

3.2.1.1 United States and Canada. PCDD emissions from stack testing of 9 facilities located in North America ranged from not detected (ND) to 22,000 ng/m^3. PCDF stack emissions for 9 facilities ranged from ND to 15,060 ng/m^3. Detection limits were not specified. Both of these upper emission values were reported in an EPA study of a modular incinerator located in Langley, Virginia. The incinerator is characterized as being susceptible to upsets caused by burning grass clippings or wet refuse stored in an open pit.[92] Two facilities are known to emit low levels of PCDD's

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[C] Resource Recovery Activities, City Currents. April 1985.

(35 to 146 ng/m^3) and PCDF's (50 to 246 ng/m^3). One is a modular unit equipped with a secondary chamber for combustion of off gases and the other uses RDF that is stored in a silo and is very dry when combusted.[49,174]

The PCDD content of fly ash samples from 21 MWI's ranged from <0.5 to 2,300 ppb. PCDF's from 14 facilities ranged from <0.5 to 3,100 ppb.

3.2.1.2 Europe. Flue gas emissions of PCDD's from eight MWI's located primarily in Italy ranged from ND to 48,900 ng/m^3. Flue gas emissions of PCDF's from seven facilities ranged from 37 to 7,460 ng/m^3. The highest PCDD and PCDF emissions were reported for six MWI's located in the Lombardy region of northern Italy.[43] The report contained no information describing feed composition, combustion design or operating conditions. However, each facility does use an ESP.

The PCDD content of fly ash samples from 31 facilities ranged from <0.5 to 3,540 ppb while PCDF's from 19 facilities ranged from ND to 1,770 ppb. Detection limits were not specified.

3.2.1.3 Japan. The PCDD content of fly ash samples from two facilities ranged from 2.4 to 4.8 ng/g.

3.2.2 Sewage Sludge Incinerators

Table 3-4 presents emissions data from two studies of sewage sludge incineration.[24,235] An unpublished study reported emissions from a single multiple hearth sludge incinerators with a water scrubber.[235] Operating temperatures were reported to be in excess of 1,000°C with a feed rate of 13 to 15.5 short tons/hour. The results were not reported in terms of specific homologues, references only to CDD's and dibenzofurans were made. For three sample periods flue gas samples contained CDD's ranging from 483 ng/m^3 to 1,140 ng/m^3 with an average of 739 ng/m^3. Dibenzofuran concentrations in flue gas samples ranged from 501 ng/m^3 to 2,248 ng/m^3 with an average of 1,213 ng/m^3. No detection limits were specified for these unpublished results.

The second study[24] analyzed emissions from incineration of aerobic sludge. Fly ash was collected by means of "dust abatement", organic vapors were trapped with a water condenser, and ashes from the combustion process were collected by grab sample. The investigators reported PCDD's to be

TABLE 3-4. SOURCE CATEGORY: SEWAGE SLUDGE INCINERATORS

Type of Facility	No. of Units Tested (Location)	Sample	PCDD/PCDF Emission Concentration and Ash Sample Content						References
			2378-TCDD		PCDD		PCDF		
			Mean	Range	Mean	Range	Mean	Range	
Multiple Hearth	1	FG	-	-	739 ng/m^3[a] (3)	483-1,140 ng/m^3	1,213 ng/m^3[a]	501-2,248 ng/m^3	235
Unspecified	1	Fumes[b]	-	-	ND[c]	-	-	-	24
		Ashes[b]	-	-	ND	-	-	-	24

"—" means no data

[a] Reported in study as "dioxins" and "dibenzofurans."

[b] Samples are listed as reported in study.

[c] Not detected

"absent" from both "ashes" and "fumes." Detection limits and information on the incinerator were not reported.

3.2.3 Fossil Fuel Combustion

Table 3-5 presents the emissions data from fossil fuel-fired combustion units.

3.2.3.1 Coal Combustion. Haile et al.[94] have reported results from research conducted as part of a nationwide study of organic emissions from utility coal combustion. Results were reported for four of the seven plants comprising the complete survey. Samples analyzed included samples from the flue gas outlet (downstream of the particulate emissions control device), fly ash emissions, and coal feed. PCDD and PCDF homologues were not identified in any sample from the four coal-fired plants. To maximize the method sensitivity, all samples were analyzed using five-day composites. Detection limits for PCDD and PCDF homologues in the flue gas analyses were 0.25 ng/m^3 for mono- through tri-CDD; 0.10 ng/m^3 for tetra-CDD; 0.50 ng/m^3 for penta-CDD and hexa-CDD; and 0.70 ng/m^3 for hepta- and octa-CDD. For solid feed and fly ash samples, detection limits for the PCDD and PCDF homologues were .025 ng/g for mono- through tri-CDD; 0.010 ng/g for TCDD; 0.050 ng/g for penta- and hexa-CDD; and 0.070 ng/g for hepta and octa-CDD.

Harless and Lewis[97] tested fly ash samples from seven coal-fired power plants and found the samples had non-detectable levels of TCDD at an average detection limit of 0.002 ng/g. Also, in an unrelated study, DeRoos and Bjorseth[59] analyzed one fly ash sample collected from a coal-fired combustion unit for TCDD's. None were detected at a detection limit of 0.002 ng/g.

These results are in agreement with those reported by Kimble and Gross[125] who analyzed stack-collected fly ash from a typical commercial coal combustion facility burning a low sulfur, high ash coal. The chlorine content of the input coal was 50 ug/g and the sample was taken downstream from the electrostatic precipitator. At a detection limit of 0.0006 ng/g, TCDD's were not detected. Kimble and Gross conclude that a fossil-fueled power plant is not a large source of TCDD. This contrasts with the conclusions presented by Dow Chemical, which analyzed fly ash samples from a coal- and oil-fired chemical plant powerhouse.[62] The results of the Dow

TABLE 3-5. SOURCE CATEGORY: FOSSIL FUEL COMBUSTION

Type of Facility	No. of Units Tested (Location)	Sample	PCDD/PCDF Emission Concentration and Ash Sample Content						References
			2378-TCDD		PCDD		PCDF		
			Mean	Range	Mean	Range	Mean	Range	
Utility Coal Boiler	4 USA	FG	-	-	ND[a]	-	ND	-	94
	4 USA	FA	-	-	ND	-	ND	-	94
Coal Boiler	7	FA	-	-	ND[b]	-	-	-	97
Coal Boiler	1	FA	-	-	ND[b]	-	-	-	59
Low Sulfur, High Ash Coal	1	FA	-	-	ND[b]	-	-	-	125
Pulverized Coal	1 Sweden	FG	ND	-	-	-	ND[c]	-	5
Coal and Oil	1 USA	Part.	ND	-	68 ng/g[e]	-	-	-	62
Coal and RDF	1 USA	FG	-	-	ND	-	ND	-	115,196
Oil-Fired, 250 MW Boiler	1 Sweden	FG	ND	-	-	-	ND[c]	-	5
Natural Gas, Residential Unit	1 USA	FA	0.6 ng/g	-	1764 ng/g[f]	-	-	-	62

" - " means no data

[a] not detected

[b] TCDD scan only

[c] Analysis for 2378 TCDF only

[d] Part.: stack particulate

[e] Penta-CDD not analyzed for

[f] Hexa-CDD, Hepta-CDD, and OCDD homologues only, analyzed for by GC-EC

study are presented below in Section 3.2.3.2. Kimble and Gross suggest the difference in TCDD emissions between their study and the Dow study may be the nature of the fuel sources, including total chlorine content.

Ahlberg _et_ _al_.[5] analyzed flue gas samples from a 265 MW pulverized coal-fired boiler equipped with an electrostatic precipitator. The boiler was firing Polish coal with a low sulfur, high ash content. No 2378-TCDD was detected at detection limits ranging from <5.4 to <6.8 ng/m^3. The 2378-TCDF isomer was not detected at detection limits ranging from <0.86 to <1.1 ng/m^3.

3.2.3.2 _Oil and Coal Combustion_. Particulates from the stack of a coal- and oil-fired powerhouse at a Dow Chemical plant were tested for PCDD emissions.[62] TCDD, hexa-CDD, hepta-CDD, and OCDD emissions ranged from 2 to 38 ng/g with TCDD's and OCDD detected at levels of 38 ng/g and 24 ng/g, respectively. The concentration of total PCDD's was 68 ng/g. The 2378-TCDD isomer was not detected. Detection limits in this study were 20 ng/g for TCDD and 10 ng/g for 2378-TCDD. Detection limits were not specified for the other homologues, which were analyzed by electron capture gas chromatography. The study did not report fuel analysis or operating conditions of the boiler.

3.2.3.3 _Oil Combustion_. Ahlberg _et_ _al_.[5] analyzed flue gas samples from a 250 MW boiler fired with a low ash, 2 percent sulfur, heavy fuel oil. The sample was taken after the heat exchanger and before the electrostatic precipitator. The 2378-TCDD isomer was not detected at detection limits ranging from <4.2 to <7.9 ng/m^3. The 2378-TCDF isomer was not detected at detection limits ranging from <0.67 to <1.3 ng/m^3.

3.2.3.4 _Natural Gas Combustion_. Dow Chemical tested particulate matter which had been removed from a home electrostatic precipitator in a residential, natural gas-fired forced-air heating system. The collected material represented the accumulation of material from six spring and summer months of operation of the precipitator. The particulate matter sample contained 34 ng/g hexa-CDD, 430 ng/g hepta-CDD, and 1,300 ng/g OCDD, for a total of 1,764 ng/g. The 2378-TCDD isomer was present at a level of 0.6 ng/g with a detection limit of 0.2 ng/g for the analysis. Other TCDD isomers were detected at a level of 0.4 ng/g, which was also the detection limit for this sample. No detection limits were specified for the other homologues which were analyzed for by electron capture gas chromatography.

3.2.3.5 Coal and Refuse-Derived Fuel Combustion. Analysis of flue gas emissions from a coal and RDF-fired facility located in Ames, Iowa, found less than detectable levels of TCDD, which was the only CDD homologue analyzed for.[115] The detection limit for TCDD was 5 ng/m^3 for vapor samples. This is a suspension-fired boiler that burns coal with 15 percent RDF. Small, uniform, 2-5 cm pieces of RDF are produced in a shredding and air classification process. The facility operates with a combustion temperature of approximately 1,200°C and produces 35 MW of electrical power from steam. The unit is reported to be operated at approximately 22 percent excess air and uses an ESP. Another study describing emissions testing at this facility reported that PCDD's and PCDF's were not detected in the flue gas.[196] The detection limit for PCDD and PCDF was 0.25 ng/m^3 for vapor samples.

3.2.4 Wood Combustion

Table 3-6 presents the emissions data for combustion units burning PCP-treated wood and firewood.

3.2.4.1 Residential Wood Combustion. Four studies have been conducted on PCDD formation from the combustion of firewood.[54,62,165,167] Ash samples were collected from 24 woodstoves and two fireplaces. The woodstoves tested were located in rural areas in three different regions of the country. Presumably the wood being burned was untreated, that is, it had not been exposed to fungicides, herbicides, or wood preservatives. For the 24 woodstoves tested, PCDD concentrations in ash samples ranged from 0.007 ng/g to 210 ng/g, with a mean concentration of 23.4 ng/g. The penta-CDD homologue was not analyzed for.[54,165] The 2378-TCDD isomer was analyzed for in 17 samples. Two samples had non-detectable levels of 2378-TCDD with detection limits ranging from 0.0009 to 0.0014 ng/g. The other 15 samples had concentrations of 2378-TCDD varying from 0.001 to 0.20 ng/g with an average concentration of 0.05 ng/g. The authors of one of the studies,[165] in which 18 woodstoves were tested, attributed some of the variability in the results to differences in woodstove design and sampling points. They also suggested

TABLE 3-6. SOURCE CATEGORY: WOOD COMBUSTION

Source Category	No. of Units Tested (Location)	Sample	PCDD/PCDF Emission Concentration and Ash Sample Content						References
			2378-TCDD		PCDD		PCDF		
			Mean	Range	Mean	Range	Mean	Range	
Residential Woodburning									
• Woodstoves	24	Ash	0.05 ng/g (15)[b]	ND[a] - 0.20 ng/g (17)	23.4 ng/g[c] (24)	0.007 - 210 ng/g	-	-	54, 165, 167
• Fireplaces	2	Ash	1.0 ng/g (1)	-	23.3 ng/g[c] (2)	1.79 - 44.7 ng/g	-	-	62
• Oil and Wood Heater	1	Ash	0.8 ng/g	-	21.7 ng/g[c]	-	-	-	62
PCP-Treated Wood Combustion									
• Controlled Air Incinerator	1	Ash FG	- -	- -	ND[d] ND[d]	- -	ND[d] ND[d]	- -	220 220
• Incinerator	1	FG (Duct)	-	-	1520 ng/m^3	-	587 ng/m^3	-	233
• Fluidized Bed System	1	FA	-	-	324 ng/g	-	241 ng/g	-	179
• Pilot Scale Incineration	1	Stack	-	-	230,870 ng/g feed (2)	111,540 - 350,200 ng/g feed	-	-	6
• Pilot Scale Incineration									
• treated wood wool	1	Smoke gases	-	-	392,000 ng/g feed (1)	-	-	-	190
• treated birch leaves	2	Smoke gases	-	-	209,150 ng/g feed (2)	205,000 - 213,300 ng/g feed	-	-	190

" - " means no data.

[a] Not Detected. Assumed to be zero for calculations.

[b] Number in parenthesis is number of samples.

[c] Penta-CDD homologue not analyzed for.

[d] TCDD/TCDF scan only.

that some of the variability could potentially be attributed to fuel contamination, although feed samples were not analyzed for PCDD content.

Ash samples from the chimneys of two fireplaces were analyzed for PCDD's.[62] One fireplace was 12 years old and one was 25 years old. The 25-year-old fireplace had total PCDD concentrations of 44.7 ng/g including 1 ng/g of 2378-TCDD. Ash samples from the 12-year-old fireplace contained 1.79 ng/g PCDD. No TCDD isomers were detected at a detection limit of 0.04 ng/g. The penta-CDD homologue was not analyzed for in either of these samples.

Ash samples scraped from the flue pipe of a residential heater combusting both oil and wood were analyzed for PCDD's. After burning only oil, the PCDD level in the ash was 0.280 ng/g. By comparison, after burning only wood, the PCDD level was 0.97 ng/g. After co-firing wood and oil, 21.7 ng/g PCDD were detected, including 0.8 ng/g of the 2378-TCDD isomer. The penta-CDD homologue was not analyzed for in any of these samples.

3.2.4.2 Treated Wood Combustion. Chlorophenols are produced for use as wood preservatives, slimacides, bactericides, and as starting material for the chlorinated phenoxy acids 2,4-D and 2,4,5-T. Chlorophenols may either be contaminated with PCDD's and PCDF's, or PCDD's can be formed by the dimerization of chlorophenates during pyrolysis. The following section discusses the results of several studies where chlorophenols were combusted with wood or wood products.

Two studies concerned the combustion of pentachlorophenol (PCP)-treated military ammunition boxes.[220,233] At the Los Alamos National Laboratory in Los Alamos, New Mexico, PCP-treated wood was incinerated under a variety of test conditions in a controlled air incinerator.[220] The incinerator had modulated burners, steam injection capability, and enhanced mixing of secondary air with the primary chamber effluent. Ash samples were taken from the hot zone between the primary and secondary combustion chambers. Neither TCDD's nor TCDF's were detected at a detection limit of 17 ng/g.

At the Tooele Army Depot in Tooele, Utah, PCP-treated ammunition boxes and explosive-contaminated wastes were incinerated.[233] The incinerator was designed to decontaminate metal parts containing explosive residue. The incinerator has an unfired afterburner (refractory lined duct) with a combustion residence time of 0.3 seconds. Four tests were performed while the incinerator was firing: 1) no waste fuels, 2) wood freshly coated with PCP, 3) 40 percent by weight PCP-treated wood and 60 percent by weight contaminated waste (including wood, cloth, metal, and rubber). Results of the analysis of stack emissions for two baseline tests showed average PCDD emissions of 5.0 ng/m^3 and average PCDF emissions of 9.82 ng/m^3. The analysis of stack emissions for three tests conducted while the 40/60 mix was fired showed average PCDD emissions of 125 ng/m^3 and average PCDF emissions of 14.2 ng/m^3. Analysis of stack emissions for three tests while freshly coated wood was fired showed average PCDD emissions of 8,215 ng/m^3 and average PCDF emissions of 426 ng/m^3. When only ammunition boxes were incinerated, afterburner samples were taken. Analysis of afterburner samples showed PCDD emissions of 1,420 ng/m^3 and PCDF emissions of 587 ng/m^3.

A pilot scale incinerator was used to burn wood chips which had been mixed with technical grade tri- and tetrachlorophenate.[6] At combustion temperatures of 500 to 800°C (932 to 1,472°F), the formation of PCDD's was demonstrated. At higher temperatures, the formation of PCDD's decreased. When wood chips and trichlorophenate were burned, stack emissions of total PCDD's were 111,540 ng/g feed. When tetrachlorophenate was burned with wood chips, stack emissions contained 350,200 ng/g feed. Addition of copper salts to the tetrachlorophenate formulation and increasing the residence time within the incinerator reduced the emission of PCDD's.

In another study, fly ash samples from a fluidized bed system burning PCP-treated wood, painted wood, and hypochlorite-treated paper were analyzed.[179] Total PCDD's and PCDF's detected in fly ash samples after burning painted wood were 177 ng/g and 217 ng/g, respectively. When PCP-treated wood was burned, PCDD levels in the fly ash were 324 ng/g and PCDF levels were 241 ng/g. When the hypochlorite-treated paper was burned, large amounts of chlorine were present but PCDD and PCDF levels were relatively low with 24 ng/g of PCDD detected and 12 ng/g PCDF detected. The addition of pentachlorophenol to these fuels did not increase PCDD or PCDF emissions.

In a pilot scale study, two chlorophenate formulations, Servarex and Kymmene KY-5, were sprayed over wood wool and birch leaves and combusted in an open fire.[190] These formulations are mixtures of 2,4,6 tri-, 2,3,4,6 tetra- and pentachlorophenate as sodium salts. PCDD's and PCDF's were detected in these two formulations at concentrations of 20 and 150 ppm, respectively. When Servarex and KY-5 were each burned separately, high levels of PCDD's were formed. When burned alone, the Servarex formed 21,600 ng/g of PCDD and the KY-5 formed 11,600 ng/g of PCDD. Each of these was then sprayed over birch leaves and wood wool and combusted in an open fire. One gram of chlorophenate was dissolved in 20 ml of water and sprayed over 30 grams of birch leaves or wood wool. Smoke gases were trapped in charcoal filters and analyzed. When birch leaves sprayed with Servarex were burned, 213,300 ng/g feed of PCDD's were formed. When wood wool and Servarex were burned, 392,000 ng/g feed of PCDD's were formed. When birch leaves and KY-5 were burned, 205,000 ng/g feed of PCDD's were formed. Purified chlorophenates were also burned with birch leaves. When 2,4,6 trichlorophenate and pentachlorophenate were burned with birch leaves, levels of PCDD's formed were 1,115,000 ng/g feed and 957,200 ng/g feed, respectively.

3.2.5 Boilers Co-firing Wastes

Table 3-7 represents the emissions data for boilers co-firing wastes. EPA's Hazardous Waste Engineering Research Laboratory (HWERL) (formerly Industrial Environmental Research Laboratory - Cincinnati (IERL)) conducted studies on industrial boilers co-firing waste products.[41] Four boilers co-firing chlorinated wastes such as creosote sludge, chlorinated solvents, and waste oil were tested. Stack emissions from three of the four boilers were tested for PCDD's at a detection limit of 1,000 ng/m^3 but none were detected. The fourth boiler was a steam generator firing waste wood contaminated with pentachlorophenol. Stack emissions of 2378-TCDD from this boiler ranged from <0.4 to <1.5 ng/m^3. Total PCDD stack emissions ranged from 74.6 to 76.4 ng/m^3 and averaged 75.5 ng/m^3.

A second study for EPA's HWERL tested waste fuels and stack gas emission samples from five industrial boiler test sites co-firing hazardous waste

TABLE 3-7. SOURCE CATEGORY: BOILERS CO-FIRING WASTES

Type of Facility	No. of Units Tested (Location)	Sample	PCDD/PCDF Emission Concentration and Ash Sample Content						References
			2378-TCDD		PCDD		PCDF		
			Mean	Range	Mean	Range	Mean	Range	
Industrial Boilers	1	FG	ND[a]	-	75 ng/m^3[b]	-	-	-	40
	4	FG	.002 ng/m^3[c] (1)	-	0.51 ng/m^3 (4)	ND - 1.1 ng/m^3	1.9 ng/m^3 (4)	0.15 - 5.5 ng/m^3	40
Industrial Boilers	3	FG	-	-	ND	-	-	-	41
	1	FG	<0.28 ng/m^3	<0.4 - <1.5 ng/m^3	75.5 ng/m^3 (2)	74.6 - 76.4 ng/m^3	-	-	41
Commercial Boilers (Spiked Waste oil)	3	FG	-	-	7630 ng/m^3[d] (3)	1400 - 17000 ng/m^3[d]	-	-	81
	3	FG	-	-	ND	-	170 ng/m^3[e]	-	81
	1	FA	-	-	911 ng/g		3777 ng/g	-	81
Industrial Boiler	1 (Switzerland)	FA	-	-	600 ng/g	-	300 ng/g	-	33
Utility Boiler	1	FG	-	-	ND	-	ND	-	96

"-" means no data

[a] Not detected

[b] PCDD's detected in feed samples

[c] 2378 TCDD detected in only 1 boiler at detection limit

[d] average and range of TCDD and OCDD from 3 different boilers

[e] TCDF detected in emission from one boiler

[f] penta through octa homologues only

fuels.[40] Among the wastes being fired were creosote sludge, carbon tetrachloride, chlorobenzene, methanol, toluene, and trichloroethylene. A watertube boiler co-firing wastes and No. 6 oil was the only boiler having detectable levels of 2378-TCDD in flue gas emissions. However, the measured value for the emission of this isomer was equal to the 0.002 ng/m^3 detection limit. This boiler also had the highest total CDF emissions of 5.5 ng/m^3 in one of two samples. A creosote sludge/wood-fired stoker had the highest total PCDD stack emissions (75 ng/m^3) but the creosote sludge co-fired with wood waste in this boiler was found to contain 7,400 ng/g of total PCDD. PCDD and PCDF homologues were not detected in any other chlorinated waste at detection limits ranging from 0.045 to 4.6 ng/g. Stack concentrations of PCDD from the other four boilers ranged from less than detectable to 1.1 ng/m^3 at detection limits ranging from 0.0022 ng/m^3 to 0.019 ng/m^3.

In another study, Buser, Bosshardt, and Rappe[33] report the identification of 600 ng/g and 300 ng/g of PCDD's and PCDF's, respectively, in the fly ash of an "industrial heating facility." This facility was generating steam by co-firing used industrial oils. PCDD's and PCDF's were detected in other fly ash samples as well but the samples with the highest concentrations were the only ones reported.

The EPA tested six commercial boilers firing spiked waste oil.[81] The boilers were in the size range of 0.4 to 25 million Btu/hr heat input capacity. The fuel was used automobile oil spiked with organic compounds such as chloroform, trichlorobenzene, chlorotoluene, and trichloroethylene at levels ranging from 1,500 ppm to 10,000 ppm.

Of the six boilers, only one had detectable levels of OCDD with 4,500 ng/m^3 and 17,000 ng/m^3 detected in one of three samples of stack gas. Detection limits were not specified for these samples. Only one of the six boilers had detectable levels of TCDF with 170 ng/m^3 detected in stack gas. Detection limits were not specified for the other samples with less than detectable levels. The feed samples of waste oil basestock and the "spiked" waste oil were tested and no PCDD's or PCDF's were detected at detection limits ranging from 0.04 ng/g to 2.0 ng/g. Fly ash samples collected from a Scotch firetube boiler did not have detectable levels of TCDD, but the concentration of penta through octa homologues ranged from not detectable to 230 ng/g. For three fly ash samples total PCDD's were 911 ng/g. Detection limits ranged from 0.5 to 10 ng/g. Concentrations of PCDF homologues ranged from not detectable to 1,000 ng/g for a total of 3,777 ng/g in three samples. Detection limits ranged from 0.5 to 10 ng/g.

A 233 MW utility boiler was tested while firing No. 6 oil and PCB-spiked waste oil.[96] The waste oil comprised 10 percent of the total fuel. PCDD's and PCDF's were not detected in stack gas emissions at detection limits ranging from 0.031 to 0.10 ug/m^3.

3.2.6 Hazardous Waste Incinerators

Table 3-8 presents the emissions data for land-based incinerators and incinerator ships.

3.2.6.1 Land-based Incinerators. Eleven incinerators firing hazardous wastes were the focus of ten studies. Among the types of units tested were rotary kilns, with and without afterburners, a mobile rotary kiln incinerator, and a tar burner. Wastes being fired typically consisted of chlorine-containing liquid organic wastes, herbicides, and wastes containing PCB's.

An incinerator was tested while firing feed containing 3,000 ug/g PCB's.[136] Cyclone outlet samples were analyzed by selective ion monitoring gas chromatograph/mass spectroscopy (GC-MS). PCDD's and PCDF's were not detected at detection limits ranging from 0.03 to 0.06 ug/m^3. Because PCDD's and PCDF's were not detected in the cyclone samples, analyses of stack samples were not performed.

One study tested two rotary kilns with afterburners.[234] Three tests each were performed at incinerator facilities at El Dorado, Arkansas, and Deer Park, Texas. Test results were reported in terms of total quantities present in the analyzed sample because leakage and loss of unknown quantities of most samples occurred during shipment preventing the calculation of actual concentrations. The facilities are operated by Energy Systems Company (ENSCO) and Rollins Environmental Services, respectively. Wastes during the first test at each facility included hydrocarbon wastes, paint and ink manufacturing wastes, pesticide process wastes, and vinyl chloride still bottoms. The Rollins facility had total TCDD and TCDF levels of 6.94 ng and

TABLE 3-8. SOURCE CATEGORY: HAZARDOUS WASTE INCINERATORS

Type of Facility	No. of Units Tested (Location)	Sample	PCDD/PCDF Emission Concentration and Ash Sample Content						References
			2378-TCDD		PCDD		PCDF		
			Mean	Range	Mean	Range	Mean	Range	
Land-based facilities:									
Fluid wall reactor	1	cyclone	-	-	ND[a]	-	ND	-	136
Rotary kiln	1 (Rollins)	FG	-	-	2.75 ng[b] (3)[c]	ND - 6.94 ng	11.8 ng[b] (3)	ND - 22ng	234
Rotary kiln	1 (ENSCO)	FG	-	-	0.37 ng[b] (3)	ND - 0.48 ng	2.7 ng[b] (3)	ND - 6 ng	234
Rotary kiln	1	FG	ND	-	75 ng/train[d] (1)	-	190 ng/train[e] (1)	-	246
Rotary kiln	1	FG	-	-	20.3 ng/m^3 (4)	9.7 - 45.5 ng/m^3	11.2 ng/m^3 (4)	2.5 - 20.3 ng/m^3	88
Rotary kiln	1 (Dow)	FG	-	-	36.6 ng/m^3	-	93.8 ng/m^3	-	153a
Incinerator w/Afterburner	1	Ash	-	-	538 ng/g (1)	-	2853 ng/g (1)	-	74
Mobile Incinerator	1	Ash	-	-	91.3 ng[f]	-	-	-	108
Rotary kiln without supplemental fuel	1 (Dow)	Part.	1870ng/g[g]	ND - 5500 ng/g	323,570[g] (3)	9,710 - 847,400 ng/g	-	-	62

(Continued)

TABLE 3-8. SOURCE CATEGORY: HAZARDOUS WASTE INCINERATORS (Continued)

Type of Facility	No. of Units Tested (Location)	Sample	PCDD/PCDF Emission Concentration and Ash Sample Content						References
			2378-TCDD		PCDD		PCDF		
			Mean	Range	Mean	Range	Mean	Range	
Tar Burner	1 (Dow)	Part.	ND (4)	-	406 ng/g[h] (4)	256 - 572 ng/g	-	-	62
Rotary Kiln with supplemental fuel	1 (Dow)	Part.	ND (5)	-	267 ng/g[h] (5)	13 - 1064 ng/g	-	-	62
Rotary Kiln	2	FG	-	-	ND	-	ND	-	161
Rotary Kiln	1	FG	-	-	ND	-	0.7 ng/m^3 [i]	-	161
Incinerator Ship		FG	-	-	ND[b]	-	-	-	1
		FG	ND	-	ND[b]	-	-	0.3 - 3 ng/m^3 [b]	

" - " means no data.

[a] Not detected. Assumed to be zero in calculations.

[b] TCDD/TCDF scan only.

[c] Number in parenthesis is number of samples used in calculations.

[d] Penta-CDD, hepta-CDD, OCDD homologues only.

[e] Penta-CDF homologue only.

[f] Loss of sample prevented concentration calculation.

[g] One of 3 tests had high results due to non-specific analytical method.

[h] Hexa-CDD, Hepta-CDD, OCDD homologues only.

[i] Penta-CDF homologue only.

13.5 ng, respectively. The second test consisted of the same wastes as the first test with the addition of liquid PCB wastes. The Rollins facility during the second test had total TCDD and TCDF levels of 1.42 ng and 22 ng, respectively. The ENSCO facility during the second test had total TCDD and TCDF levels of 0.48 ng and 6 ng, respectively. For the third test, liquid PCB wastes were fired with clean fuel oils. The Rollins facility had less than detectable TCDD's at detection limits ranging from 0.48 to 0.9 ng and 2 ng for TCDF. The ENSCO facility had less than detectable levels of TCDD and TCDF at detection limits of 0.2 to 0.45 ng for TCDD's and from 0.08 to 0.5 ng for TCDF's.

A rotary kiln operating at 1,200°C was tested while burning Silvex herbicide.[246] The 2378-TCDD isomer was not detected at a detection limit of 1 ppb (by volume). The penta-CDD, hepta-CDD, and OCDD homologues were detected at a total of 75 ng/MM5 train. The penta-CDF homologue was present at a concentration of 190 ng/MM5 train.

In an unrelated study, stack emissions from a rotary kiln operating at 1,200°C were analyzed.[88] Four tests were conducted while PCB's were being incinerated. The average concentrations of PCDD's and PCDF's were 20.3 and 11.2 ng/m^3, respectively. However, TCDD's and OCDD's were the primary homologues detected. Detection limits for the other homologues were not reported.

The incinerator exhaust of the rotary kiln waste incinerator at Dow Chemical was tested.[153a] This incinerator destroys 20 tons/day of liquid waste in the 1,025°C afterburner and 185 tons/day of solid and liquid combustible trash including 1.5 tons/day of chlorophenolic wastes from the 2,4-dichlorophenol and 2,4-D processes. The average concentrations of PCDD's and PCDF's detected in three test runs were 36.6 ng/m^3 and 93.8 ng/m^3, respectively.

At another facility, used transformer oil (supposedly containing less than 50 ppm PCB's) is fired in an incinerator.[74] A spot check on the used oil detected one sample with 90 ppm PCB's. The incinerator, which has secondary combustion chambers and an afterburner, burns off the insulation from the aluminum or copper windings from dismantled transformers. One composite ash sample was analyzed and found to contain 538 ng/g PCDD's and 2,853 ng/g PCDF's.

A mobile incinerator was tested while firing CDD-contaminated liquid still bottoms and soil during one test and CDD-contaminated lagoon sediment (containing 1-21 ppb 2378-TCDD) during a second test.[108] The only homologue detected was OCDD at a total of 91.3 ng/g in three samples. These detectable levels were suspected to be from contaminated solvent used in the analyses. It was unlikely the OCDD was formed during the incineration process.

Dow Chemical tested an industrial solid waste incinerator (rotary kiln) and a tar burner.[62] The tar burner was a 72 million Btu/hr unit with natural gas burned as a supplemental fuel. Four tests were conducted while the unit was firing natural gas and tars. The 2378-TCDD isomer and other TCDD's were not detected in particulate matter samples. Detection limits ranged from 1.3 to 3.0 ng/g for the 2378-TCDD isomer and from 0.7 to 1.2 ng/g for other TCDD's. Total concentrations of the hexa-CDD, hepta-CDD, and OCDD homologues ranged from 256 to 572 ng/g for the four tests with an average of 406 ng/g. The penta-CDD homologue was not analyzed for.

The rotary kiln incinerator Dow Chemical tested was a 70 million Btu/hr unit. This unit is capable of incinerating both solids and liquids. Supplemental fuel is also burned in this unit in the rotary kiln and the secondary combustion chamber to maintain combustion temperatures. Three tests were performed while the kiln was burning tars, solid waste, and natural gas, but without supplemental fuel in the secondary combustion chamber. Particulate matter from the first test was analyzed for PCDD's using a nonspecific GC-MS packed column method and very high levels of 2378-TCDD were detected. In the other two tests, a capillary column specific for 2378-TCDD was used, so the results of the first test are not comparable with the second and third test. During the first test, an average of 5500 ng/g of 2378-TCDD was detected in particulate matter. The average total concentration of other TCDD's and the hexa-CDD, hepta-CDD and OCDD homologues in the first test was 847,400 ng/g. The total concentration of PCDD's (not including penta-CDD) for the other two tests were 9,710 and 113,600 ng/g. The 2378-TCDD isomer was detected in the second test at a concentration of

110 ng/g. This isomer was not detected in the third test but the detection limit was 260 ng/g.

Five tests were then conducted on this rotary kiln while oil and natural gas, and tars and natural gas were fired as supplemental fuel in the secondary combustion chamber. The 2378-TCDD isomer and other TCDD's were not detected in particulate matter from any of the five tests. Detection limits ranged from 2 to 5 ng/g for the 2378-TCDD isomer and from 2 to 8 ng/g for the other TCDD isomers. Total concentrations of the hexa-CDD, hepta-CDD, and OCDD homologues ranged from 13 to 1,064 ng/g with an average for the five tests of 267 ng/g. The penta-CDD homologue was not analyzed for.

Results from three tested rotary kilns were reported in one study.[161] Only one of the kilns had detectable TCDF emissions at a concentration of 0.7 ng/m^3. However, TCDF's were detected in the fuel, which was liquid organic waste containing 0.4 to 1 percent chlorine. The other two kilns were firing liquid organic solvents with chloride concentrations ranging from 0.2 to 16 percent chlorine. No TCDD's or TCDF's were detected in the flue gas or feed. Detection limits were unavailable.

3.2.6.2 Incinerator Ships. Two studies were conducted with the M/T Vulcanus incinerator ship.[1,2] The first study was conducted during the incineration of Herbicide Orange contaminated with 2378-TCDD.[1] The incinerators were heated up to a flame temperature of 1280°C with fuel oil before the burner was changed over to the Herbicide Orange feed. TCDD levels in the feed ranged from less than detectable to 2,800 ng/ml, with an average concentration of 1,820 ng/ml injected. The detection limit for the feed samples was 20 ng/ml injected. No TCDD's were detected in the stack emissions. Detection limits for the TCDD's were very variable due to the complexity of the samples. Detection limits ranged from 0.0009 ng/ml injected to 0.086 ng/ml injected into the GC-MS for analysis.

The second study was conducted during a PCB burn.[2] TCDD's, including the 2378-TCDD isomer, were not detected in the feed or in stack emissions. Detection limits ranged from 2 to 22 ng/g. TCDF's were detected in all samples of waste and in several samples of stack gas. The analytical method could not distinguish the 2378-TCDF isomer from the other 37 TCDF isomers.

Total concentrations of TCDF's in stack gas samples were reported to range from <0.3 to <3 ng/m^3.

3.2.7 Lime/Cement Kilns

Table 3-9 presents emissions data for lime/cement kilns.

Four studies have addressed PCDD and PCDF emissions from lime or cement kilns co-firing wastes.[20a,20b,58a,184] The combustion temperature of this process is about 1500^{o}C with a typical residence time of 1.5 seconds.

A cement kiln at San Juan Cement was tested while co-firing liquid organic wastes containing from 6.5 to 35.5 percent chlorine (by weight).[184] Flue gas and particulate samples were taken. One of the four SASS train samples had detectable levels of hexa-CDF and hepta-CDF. The concentrations of these two homologues were 1.35 ng/m^3 and 0.74 ng/m^3, respectively. None of the other homologues were detected at detection limits ranging from 1.6 to 4.9 ng/m^3. Similarly, one of the EPA Method 5 filters used for particulate analysis contained 11.0 ug/m^3 of penta-CDF, 25.7 ng/m^3 hexa-CDF, and 8.1 ng/m^3 hepta-CDF. None of the other particulate samples had detectable PCDF's at detection limits ranging from 5 to 15 ng/filter. These detectable emissions occurred when the kiln was fed waste containing 21.4 percent chlorine which corresponds to a chlorine input of 3.5 percent of total fuel input. This resulted in a potentially kiln-damaging condition. The study maintains the detectable emission occurred only during "upset" conditions. Under other conditions PCDF's were not emitted, and PCDD's were not emitted under any condition including the "upset" conditions. Detection limits ranged from 1.6 to 4.9 ng/m^3 for stack gas emissions, and from 5 to 15 ng/filter for the particulate analysis.

A wet-process cement kiln at General Portland Cement, Inc., and a dry-process cement kiln at Lone Star Cement were tested.[20a,20b] Both of these facilities were co-firing hydrocarbon solvents, chlorine-containing wastes, and wastes spiked with Freon 113. No PCDD's or PCDF's were detected in stack emissions at the detection limit of 1 ng/ul injected (into the GC-MS for analysis).

A lime kiln at Rockwell Lime Company was tested while firing petroleum coke and waste fuel consisting of lacquer thinner solvents, alcohols, and

TABLE 3-9. SOURCE CATEGORY: LIME/CEMENT KILNS

Type of Facility	No. of Units Tested (Location)	Sample	PCDD/PCDF Emission Concentration and Ash Sample Content						References
			2378-TCDD		PCDD		PCDF		
			Mean	Range	Mean	Range	Mean	Range	
Cement kiln (San Juan Cement)	1	FG	-	-	ND[a]	-	2.09 ng/m^3 (1)	-	184
		Part.	-	-	-	-	44.8 ng/m^3	-	184
Cement kiln (General Portland)	1	FG	-	-	ND	-	ND	-	20a
Cement kiln (Lone Star Cement)	1	FG	-	-	ND	-	ND	-	20b
Lime Kiln (Rockwell Lime)	1	Part.	-	-	ND	-	ND	-	58a
		Baghouse Dust	-	-	ND	-	ND	-	58a

" - " means no data.

[a] ND - Not detected

paint wastes.[58a] The wastes contained approximately 3 percent chlorine (by volume). PCDD's were not detected in baghouse dust or EPA Method 5 filters. For baghouse dust samples, detection limits ranged from 0.005 to 0.25 ng/g. For EPA Method 5 filters, detection limits were converted to stack gas concentration and ranged from 0.034 to 2.0 ng/m^3.

3.2.8 Hospital Incinerators

Table 3-10 presents emissions data from hospital incinerators.

High temperature incineration is the preferred method for disposal of hospital wastes containing infectious or hazardous materials. Most hospital incinerators of older design are incapable of destroying all hazardous materials and have inefficient combustion leading to emission of hazardous air pollutants. Hospital wastes are also highly variable in content. They usually contain 20 percent plastics, compared to municipal solid waste which contains 3 to 7 percent plastics. Combustion of plastics composed of polyvinyl chloride and other halogenated polymers and copolymers can be a major generator of toxic air emissions.

A 1983 stack test on a Canadian hospital incinerator found PCDD's and PCDF's to be emitted at average levels of 69 ng/m^3 and 156 ng/m^3, respectively.[31a] The test was performed on a high combustion efficiency controlled-air, two-chamber incinerator. Small amounts of PCDD's and PCDF's were detected in the bottom ash, with much higher levels in the fly ash.

Doyle _et al_.[62a] reported results from three hospital incinerators in the United States. Stack test filter samples were analyzed and had average levels of PCDD's and PCDF's of 15 ng/m^3 and 25 ng/m^3, respectively. According to Doyle _et al_., these levels probably represent less than one-half the actual emissions because more than 50 percent of PCDD's and PCDF's can be found in the vapor phase, which was not analyzed in these particulate screening tests.

3.2.9 Wire Reclamation Incinerators

Table 3-11 presents emissions data from one study conducted on a wire reclamation incinerator.[103] Wire insulation incinerated during this process often contains PCB's and polyvinyl chloride. Analyses of inorganics in the stack and furnace samples from the three furnaces revealed high levels of

TABLE 3-10. SOURCE CATEGORY: HOSPITAL INCINERATORS

Type of Facility	No. of Units Tested (Location)	Sample	PCDD/PCDF Emission Concentration and Ash Sample Content						References
			2378-TCDD		PCDD		PCDF		
			Mean	Range	Mean	Range	Mean	Range	
Canadian	1	FG	-	-	69 ng/m^3 (1)	52 - 84 ng/m^3	156 ng/m^3 (1)	117 - 197 ng/m^3	31[a]
U. S.	3	FG			15 ng/m^3 (3)	-	25 ng/m^3 (3)	-	62[a]

" - " means no data

TABLE 3-11. SOURCE CATEGORY: WIRE RECLAMATION INCINERATORS

Type of Facility	No. of Units Tested (Location)	Sample	PCDD/PCDF Emission Concentration and Ash Sample Content						References
			2378-TCDD		PCDD		PCDF		
			Mean	Range	Mean	Range	Mean	Range	
Wire Reclamation Incinerator	1 Midwestern USA	FA (Stack)	-	-	0.41 ng/g[a]	-	11.6 ng/g[a]	-	103
		ASH (Furnace)	-	-	0.58 ng/g[a]	-	0.73 ng/g[a]	-	103

" - " means no data

[a] TCDD and TCDF scans only.

copper and lead as well as 85,500 ppm of chloride in one of the furnace samples.

Total TCDD and total TCDF concentrations in stack fly ash scrapings were 0.41 ng/g and 11.6 ng/g, respectively. Bottom ash samples from the furnace contained 0.058 ng/g total TCDD's and 0.730 ng/g total TCDF's. The analyses did not distinguish the 2378-TCDD or 2378-TCDF isomers; only total TCDD's and TCDF's were measured.

3.2.10 PCB Fires

Table 3-12 presents emissions data concerning several studies. In September 1978, 18 capacitors containing PCB's were burned in a fire at a transformer station near Stockholm, Sweden.[110] Several types of samples were taken. Liquid from inside an exploded capacitor contained 75,000 ng/g PCDF.

In Binghamton, New York, in 1981, an electrical transformer containing about 1,100 gallons of PCB's was involved in an explosion.[60] Total PCDF homologues in soot were initially found to be as high as 2,160,000 ng/g. The 2378-TCDF isomer accounted for 12,000 ng/g of total PCDF's. The hexa-CDF homologue alone accounted for 965,000 ng/g of total PCDF's. Total PCDD's were found at a concentration of 20,000 ng/g including 600 ng/g 2378-TCDD.

In January 1982, an electrical fire involving PCB's broke out in a Boston, Massachusetts, office building.[60] One bulk soot sample contained a total of 115,000 ng/g PCDF's including 60,000 ng/g TCDF. No PCDD's were detected at a detection limit of 100 ng/g.

In March 1982, a fire broke out in a capacitor battery in a metal treatment factory in Skovde, Sweden.[192] The capacitors contained mineral oil and PCB's. Wipe tests were taken from several locations and results were reported in terms of unit area. Samples taken from the floor, 0.5 meters from the capacitor, had the highest levels of PCDF's with 100 ng/m^2 2378-TCDF and 772 ng/m^2 PCDF's.

In Miami, Florida, during April 1982, a fire and explosion occurred when an underground transformer vault exploded releasing approximately 100 gallons of PCB transformer oil onto the floor.[99] Smoke ejector fans were set up to ventilate the vault. Samples of soot and other residue from the fire were collected. Wipe samples were also taken from surfaces near the fire scene.

TABLE 3-12. SOURCE CATEGORY; PCB FIRES

Type of Facility	No. of Units Tested (Location)	Sample	PCDD/PCDF Emission Concentration and Ash Sample Content						References
			2378-TCDD		PCDD		PCDF		
			Mean	Range	Mean	Range	Mean	Range	
Capacitor Battery	1 Stockholm	Liquid	-	-	-	-	75,000 ng/g	-	110
Transformer Vault	1 Binghamton, NY	Soot	600 ng/g	-	19,400 ng/g	-	2,160,000 ng/g	-	60
Transformer Vault	1 Boston, MA	Soot	-	-	ND	-	115,000 ng/g	-	60
Capacitor Battery	1 Skovde, Sweden	Wipes	-	-	-	-	772 ng/m^2	-	192
Transformer Vault	1 Miami, FL	Soot	-	-	ND[b]	-	1710 ng/g	-	99
Capacitor Battery	1 Surahammar, Sweden	Wipes	-	-	-	-	7480 ng/m^2 (2)[a]	4060 - 10,900 ng/m^2	76
Transformer Vault	1 San Francisco, CA	Soot	59 ng/g	-	324 ng/g[c]	-	28,900 ng/g[c]	-	158
Transformer Cores	1 Washington State	Ash	-	-	5.2 ng/g[d]	-	41.4 ng/g	-	218

" - " means no data

[a] Number of samples

[b] Not detected

[c] TCDD/TCDF scan only

[d] Hepta-CDD and OCDD homologues only

Four bulk samples of soot and other residue, and three hexane wipe samples were analyzed. No PCDD's were detected in these samples at a detection limit of 10 ng/g. PCDF's from tri-CDF to hexa-CDF were detected in two of the six samples. The soot and dust sample taken from a cable support bracket contained 1,710 ng/g tetra- through octa-PCDF homologues. Soot taken from the ejector fan contained 670 ng/g tetra- through octa-PCDF homologues. The 2378-TCDF isomer was not detected at detection limits of 10 ng/g and 100 ng/g.

In September 1982, molten steel at a steel mill in Surahammar, Sweden, ignited a 500-unit capacitor battery.[76] The capacitors were filled with two tons of PCB's and three tons of mineral oil. Wipe samples from several locations were analyzed. Results were reported in terms of unit area. Two samples from the capacitor room had an average of 620 ng/m^2 2378-TCDF and an average 7,480 ng/m^2 of tetra- through octa-PCDF homologues.

In 1983, in San Francisco, California, a fire started in a transformer vault containing three transformers filled with PCB's.[158] It was reported that only one transformer leaked. The liquid remaining contained 127 ng/g total TCDD's and 59 ng/g 2378-TCDD.

A fire in Washington State in 1984, involved transformer oil and cores.[218] A grab sample of the ash was analyzed and found to contain 41.4 ng/g PCDF's and 2.7 ng/g and 2.5 ng/g of the hepta-CDD and OCDD homologues, respectively.

3.2.11 Automobile Emissions

Table 3-13 presents data from automobiles.

Dow Chemical and the U. S. EPA each conducted a study on emissions from automobiles.[62,213] Dow Chemical collected particulate solids from seven types of mufflers. Results were reported for three cars burning gasoline and two trucks using diesel fuel. Samples were analyzed by GC-MS and GC-EC. Results from the GC-MS analyses are reported here except where noted. Samples from one car which used leaded gasoline and no catalytic converter had no detectable 2378-TCDD and 0.004 ng/g other TCDD's. The detection limit for the 2378-TCDD isomer was 0.002 ng/g. Hexa-CDD and hepta-CDD were not

TABLE 3-13. SOURCE CATEGORY: AUTOMOBILE EMISSIONS

Type of Facility	No. of Units Tested (Location)	Sample	PCDD/PCDF Emission Concentration and Ash Sample Content						References
			2378-TCDD		PCDD		PCDF		
			Mean	Range	Mean	Range	Mean	Range	
Automobiles Burning:									
Leaded Gas	1	Scraping	ND[a]	-	0.004 ng/g[c] (1)[b]	-	-	-	62
Leaded Gas	3	Filter Extract	2.98 ng/g	-	47.7 ng/g[d]	-	-	-	213
Unleaded Gas/ Catalyst	1	Scraping	ND	-	0.08 ng/g[c]	-	-	-	62
Unleaded Gas/ Catalyst	10	Filter Extract	1.4 ng/g (1)	-	37.4 ng/g[d] (1)	-	-	-	213
Unleaded Gas/ Chevette	1	Filter Extract	0.28 ng/g (1)	-	7.5 ng/g[d] (1)	-	-	-	213
Unleaded Gas/ Catalyst/ Low Mileage	1	Scraping	ND	-	0.01 ng/g[c,e]	-	-	-	62
Diesel Truck	2	Scraping	0.0015 ng/g (2)	ND - 0.003	0.395 ng/g (2)	0.39 - 0.40 ng/g	-	-	62
Diesel Car	2	Filter Extracts	ND	-	ND[d]	-	-	-	213

" - " means no data

[a] Not detected, assumed to be zero for calculations

[b] Numbers in parentheses are number of samples calculations are based on.

[c] Analysis for TCDD, Hexa-CDD, Hepta-CDD, and OCDD only

[d] TCDD scan only

[e] Analysis of Hexa-CDD homologue by GC-EC was not confirmed by GC-MS

detected at detection limits of 0.014 ng/g and 0.006 ng/g, respectively, while 0.016 ng/g of the OCDD homologue were present.

The second car had been burning unleaded gasoline and was equipped with a catalytic converter. The 2378-TCDD, other TCDD's and hexa-CDD were not detected at detection limits of 0.003 ng/g, 0.001 ng/g, and 0.01 ng/g, respectively. The hepta-CDD and OCDD homologues were detected at levels of 0.014 ng/g and 0.068 ng/g, respectively.

The third car sampled was burning unleaded gasoline with a catalytic converter and had relatively low mileage (~15,000 miles). The 2378-TCDD isomer was not detected at detection limits of 0.0002 ng/g. Concentration of the other TCDD's were 0.0001 ng/g which equaled the detection limit. The hexa-CDD homologue was detected at 0.0005 ng/g by electron capture gas chromatography (GC-EC) but these results were not confirmed by GC-MS analysis. GC-EC analysis of the particulate matter samples detected 0.002 ng/g hepta-CDD and 0.008 ng/g OCDD. These positive results were confirmed by GC-MS.

For samples from one of the diesel mufflers, GC-MS analysis did not detect 2378-TCDD, other TCDD's or hexa-CDD at detection limits of 0.003 ng/g, 0.007 ng/g, and 0.025 ng/g, respectively. Levels of hepta-CDD and OCDD were 0.110 ng/g and 0.280 ng/g, respectively. The second diesel muffler had 0.003 ng/g 2378-TCDD, 0.02 ng/g TCDD, 0.02 ng/g hexa-CDD, 0.10 ng/g hepta-CDD, and 0.26 ng/g OCDD.

The U. S. EPA analyzed four composites of filter extracts from several automobiles. Each of the extracts was analyzed by GC-MS with a detection limit of 0.04 ng. Results were reported in terms of ng per sample with the weight in grams of the sample also noted. For the purposes of this report the reported values were recalculated to reflect the concentration of TCDD's in ng/g.

A pooled sample from two diesel cars contained no detectable 2378-TCDD or other TCDD's. Pooled filter extracts from three cars burning leaded gasoline contained 2.98 ng/g of the 2378-TCDD isomer and 47.7 ng/g of four other unspecified TCDD isomers. Samples from 10 cars with catalysts burning unleaded gasoline comprised the third sample. The 2378-TCDD isomer was detected at a concentration of 1.4 ng/g. Nine other TCDD isomers were detected at a concentration of 37.4 ng/g. The fourth sample was composed of a filter extract from a catalytic car burning unleaded gasoline. The car was malfunctioning and had excessive oil consumption. It was tested separately because its extractable particulate emissions were so high its full inclusion in the catalyst pool would have skewed the data. It was included in the catalyst composite pool at one-tenth its normal emission rate. Particulate extracts from this vehicle contained 0.28 ng/g 2378-TCDD and 7.5 ng/g of 10 other unspecified TCDD isomers.

3.2.12 Activated Carbon Regeneration Furnaces

Table 3-14 presents two studies which were conducted on activated carbon regeneration at the Cincinnati Waterworks, Cincinnati, Ohio.[13,156] The first study tested emissions from the fluidized bed system before an afterburner was installed.[13] The carbon regenerated during the first study had been in service for approximately one year. Pre-chlorination of the wastewater (relative to the granular activated carbon bed) was in use.

Concentrations of 2378-TCDD in the flue gas ranged from 0.01 to 0.21 ng/m^3 with an average of 0.1 ng/m^3. TCDD concentrations in the flue gas ranged from 0.06 to 0.3 ng/m^3 with an average concentration of 0.17 ng/m^3. Flue gas concentrations of TCDF ranged from 0.08 to 0.51 ng/m^3 with an average of 0.3 ng/m^3. For particulate samples, concentrations of the 2378-TCDD isomer ranged from 4.3 to 51 ng/g with an average of 25 ng/g. Concentrations of TCDD ranged from 36 to 66 ng/g with an average concentration of 48 ng/g. For TCDF's, concentrations ranged from less than detectable to 245 ng/g with an average concentration of 103 ng/g in particulate samples. The detection limit for TCDF's was 4 ng/g.

The second study at this facility took place after installation of an afterburner.[156] The afterburner is located in the off-gas stream from the fluidized bed reactivation unit. The average temperature of the afterburner during the test period was 2500°F. Post-chlorination of the wastewater (relative to the granular activated carbon bed), rather than pre-chlorination, was in use during the second study. The carbon being regenerated had been in use 200 days.

TABLE 3-14. SOURCE CATEGORY: ACTIVATED CARBON REGENERATION

Type of Facility	No. of Units Tested (Location)	Sample	PCDD/PCDF Emission Concentration and Ash Sample Content						References
			2378-TCDD		PCDD		PCDF		
			Mean	Range	Mean	Range	Mean	Range	
Fluidized Bed w/o Afterburner	1	FG	0.1 ng/m^3 (4)[a]	0.01 - 0.21 ng/m^3	0.18 ng/m^3 (4)	0.06 - 0.3 ng/m^3	0.3 ng/m^3 (4)	0.08 - 0.51 ng/g^3	13
		Part.	25 ng/g (4)	4.3 - 51.2 ng/g	48 ng/g (4)	36 - 66 ng/g	103 ng/g (4)	ND[b] - 245 ng/g	13
Fluidized Bed w/ Afterburner	1	FG (Stack)	ND	-	1.58 ng/m^3 [c]	-	0.05 ng/m^3 [d]	-	156
		FG (Recup)	ND	-	1.59 ng/m^3 (4)	ND - 3.71 ng/m^3	1.37 ng/m^3 (4)	0.015 - 4.76 ng/m^3	156
		FG (Afterburner) 1 sec.	ND	-	.012 ng/m^3 [e]	-	0.44 ng/m^3	-	156
		FG (Afterburner) 2 sec.	ND	-	0.7 ng/m^3 (2)	ND - 1.4 ng/m^3	0.29 ng/m^3 (2)	0.19 - 0.39	156

" - " means no data

[a] Number in parenthesis is number of samples used for calculations

[b] Not detected

[c] Hepta-CDD and OCDD homologues only

[d] Hexa-CDF, Hepta-CDF, OCDF homologues only

[e] TCDD scan only

Emissions from the stack, afterburner, and recuperator were tested. The 2378-TCDD isomer was not detected in any of the samples. PCDD levels in stack samples were 1.58 ng/m^3, but only the hepta-CDD and OCDD homologues were present. PCDF concentrations in stack samples were 0.5 ng/m^3. In these samples, the hexa-CDF, hepta-CDF and OCDF homologues were present. Detection limits for these samples were not specified. However, information was available for sample MM5 train blanks and sample train volumes making calculation of detection limits possible. The calculated detection limit for the 2378-TCDD and other TCDD isomers was 0.006 ng/m^3. For the TCDF isomers, the calculated detection limit was 0.007 ng/m^3.

3.2.13 Experimental Studies

Experimental studies have been conducted on PCDD and PCDF formation from combustion of chlorinated aromatics (see Table 3-15). Chlorobenzenes, chlorophenols and the effect of inorganic chlorine on PCDD emissions have been studied. Buser investigated the formation of PCDD's and PCDF's from the pyrolysis of chlorobenzenes.[34] Both PCDD's and PCDF's were detected in pyrolyzed samples. The formation mechanism proposed included a chlorophenol intermediate. Buser also investigated the formation of PCDF's from pyrolysis of PCB's.[35,36,37] The yields of PCDF's were estimated to range from 0.1 percent to several percent. The proposed mechanism is an intramolecular cyclization.

In a pilot incineration study, Jansson combusted chlorophenol-treated wood.[111] PCDD's were detected at levels ranging from 0.2-155 ug/g feed.

Three reports have dealt with PCDD formation from combustion processes in the presence of inorganic chlorine.[145,149,226] Tiernan et al. found no detectable PCDD's or PCDF's emitted from the combustion of virgin pine.[226] However, in the presence of HCl, significant quantities of TCDD's were detected. Mahle et al. present similar results when burning coal in the presence of Cl_2, HCl, and NaCl.[149] Liberati et al. studied the combustion of vegetables.[145] When inorganic chlorine or polyvinyl chloride (PVC) is added, PCDD's and PCDF's were detected in the emissions.

Chlorophenol combustion was studied at various combustion temperatures and residence times by Environment Canada.[200] Combustion of 2,4,5-TCP,

TABLE 3-15. SOURCE CATEGORY: EXPERIMENTAL

Type of Facility	No. of Units Tested (Location)	Sample	PCDD/PCDF Emission Concentration and Ash Sample Content						References
			2378-TCDD		PCDD		PCDF		
			Mean	Range	Mean	Range	Mean	Range	
Quartz Mini Ampule (Trichlorobenzene pyrolysis)	1	FG	-	-	197 ng/samp (5)[a]	45-370 ng/samp	1081 ng/samp (5)	291 - 1815	34
Pilot Incineration (Chlorophenol Treated Wood)	1	FG	-	-	24 ug/g feed (20)	0.1 - 155 ug/g feed	-	-	111
Vegetable Combustion (Vegetables + Cl)	1	FG	-	-	36 ug/g feed	2 - 101 ug/g feed	31 ug/g feed (8)	6 - 74 ug/g feed	145
Quartz tube (Coal + Air + HCl)	1	FG	-	-	103 ng/g feed (4)	1.2 - 290	-	-	149
Chlorophenol Combustion	1	FG	-	-	307 ug/g feed[b] (49)	0.6 - 3400 ug/g feed	-	-	200

" - " means no data

[a] Numbers in parenthesis indicate number of samples calculations are based on.

[b] PCDD/PCDF data combined.

Alchem 4135, Woodbrite 24, and diptank sludge generated from Woodbrite 24 preservation resulted in PCDD concentrations in flue gas ranging from 0.6-3400 ug/g feed.

3.3 PCDD FORMATION HYPOTHESES AND FACTORS AFFECTING EMISSIONS FOR COMBUSTION SOURCES

This section presents a summary of the most common PCDD formation hypotheses for PCDD emissions from combustion sources. The section summarizes the hypotheses contained in the literature and also presents a discussion of combustion device operating parameters and fuel characteristics that may affect PCDD emissions.

3.3.1 A Summary of Formation Hypotheses for PCDD from Combustion

One of the earliest combustion device PCDD formation hypotheses advanced was that of Dow Chemical Company entitled "The Trace Chemistries of Fire--A Source of and Routes for the Entry of Chlorinated Dioxins into the Environment."[31,62] This hypothesis was advanced based on sampling conducted by Dow Chemical Company on samples taken from around the Midland facility and sampling of a wide range of combustion devices.

This hypothesis suggested that PCDD's/PCDF's in combustion effluents were ubiquitous and were due to the trace chemistries of fire. This hypothesis, in conjunction with the findings of PCDD/PCDF in ashes and stack gases from municipal solid waste combustors, led to the inclusion of combustion sources in the National Dioxin Study.

A significant amount of effort has been expended in an attempt to explain how or why PCDD's/PCDF's are formed in combustion processes. Table 3-16 summarizes hypotheses contained in the literature. Much of the effort has been directed toward municipal solid waste incinerators. A significant number of studies and hypotheses have tried to link specific precursors with PCDD formation. The most prevalent precursors cited include chlorinated phenols and chlorobenzenes. A considerable amount of work has also focused on the chlorine content of the fuel. None of the hypotheses advanced to date have been proven.

TABLE 3-16. SUMMARY OF PCDD/PCDF FORMATION HYPOTHESES

Dioxin Formation Hypothesis/Author	Source Categories or Fuels Under Consideration	Key Variables or Factors Affecting Dioxin Formation and Emission	Data Base References
Trace Chemistries of Fire Bumb, Crummett	All Combustion Sources	Numerous chemical reactions o Combustion seldom more than 99.9% efficient o Refuse and fossil fuels are complex o Natural chlorine content; 1-5000 ppm o Transition metals in ash o Chlorinated phenols and chlorobenzenes	31
Shih et al.	Fossil fuels, wood, coal, refuse in utility, industrial and commercial boilers	Molecular structure of fuel Chlorine content Presence of precursors Combustion conditions: o temperature, residence time Mixing efficiency and air/fuel ratio	210
Precursor Hypothesis Esposito, et al.	Combustion of wastes	Precursors: chlorophenols, chlorobenzenes, PCB's	78
Rappe, et al. Jansson, et al. Ahling, et al.	Experimental studies; combustion of chlorinated phenols	Combustion temperature o 500-800°F	190, 111, 6, 7
Buser, et al.	Pyrolysis of chlorobenzenes Pyrolysis of PCB's		34 36
Tiernan, et al.	Wood	Addition of HCl	226
Mahle and Whiting	Coal	Inorganic Chlorine: Cl_2, HCl, NaCl	149
Liberti, et al.	Vegetables	Addition of inorganic chlorine or PVC	145
Post flame catalytic reactions Shaub	Municipal solid waste	Availability of active sites on particulate Temperature (above 1400°F) Chlorination of lignin on grate Uniform temperature & mixing with combustion air	207
"New Theory" Griffin	Municipal solid waste/coal combustion	Chlorine to sulfur ratio Chlorination of aromatic rings via Cl_2 gas	--
Commoner, et al. Gas phase synthesis after combustion	Municipal solid waste	Availability of Cl_2 derived from PVC Oxidative Combustion Processes	48
Niessen	Municipal solid waste	HCl from oxidation of PVC Unchlorinated precursor: lignin Chlorination of precursor in gas flow path above grate	170

3.3.2 Factors Affecting PCDD Emissions From Combustion Sources

This section discusses the following factors identified in the literature that may affect PCDD emissions:

- PCDD in feed,
- precursors in feed,
- chlorine in feed,
- combustion temperature,
- residence time,
- oxygen availability,
- feed processing, and
- supplemental fuel.

The interaction of these factors during the formation of PCDD's is not well defined. Therefore, each of the factors is discussed separately below.

3.3.2.1 PCDD in Feed. 2378-TCDD is an impurity that results from the manufacture of trichlorophenol, which is used to make the herbicide 2,4,5-trichlorophenoxy acetic acid (245-T). Pentachlorophenol (PCP) production will also result in a PCDD contaminant, primarily OCDD. The primary end use for PCP is as a wood preservative. It is anticipated that limited PCDD contamination will also occur during the manufacturing of other similar chlorinated aromatics, particularly if the manufacturing process is inefficient or not well controlled. Therefore, PCDD's are expected to enter the environment as a contaminant of commercial products, such as wood preservatives and pesticides.

The widespread use of these products increases the possibility of finding PCDD's in the feed of a combustion process. For example, PCP-treated wood may be used to fire boilers. Runoff may carry pesticides to water treatment facilities where the organics are incorporated into a sludge. The sludge may then be incinerated. Likewise, contaminated waste streams from manufacturing processes may be incinerated as an energy recovery procedure. One example is PCP sludge incinerators used at wood preserving facilities.

If PCDD's are found in the feed of an inefficient or poorly controlled combustion process, it is very likely that they will be released to the atmosphere.

3.3.2.2 Precursors in Feed. Although the Dow "Chemistry of Fire" theory is backed by a considerable amount of experimental data, many of the reviewed studies focused on the formation of PCDD's and PCDF's from precursors. Experiments by Buser, Rappe, and others are described in more detail in Section 3.2.11. Esposito *et al*. presented detailed descriptions of the formation mechanisms of chlorinated CDD's from precursors.[78] This work organizes CDD precursors into three classes:

- Class I - Polyhalogenated phenols, primarily with a halogen ortho to the hydroxyl group, with a high probability of CDD formation.
- Class II - Ortho-halophenols and ortho-halophenyl esters where the substituted groups are a mixture of halogens and nonhalogens.
- Class III - Other chemicals having the possibility, but less likelihood, of CDD formation. These include chlorinated aromatic compounds.

The majority of experimental work to date has centered on three classes of precursors: chlorinated phenols, chlorinated benzenes, and PCB's.

PCDD formation from the combustion of chlorinated phenols has been tested extensively by Rappe[190], Jansson[111], and Ahling[6,7]. Dechlorination of the highly chlorinated homologues can result in the more toxic TCDD isomers. Chlorinated phenols are used as wood preservatives, herbicides, and sap stain control. Wood or vegetation sprayed with chlorophenols may be disposed of by incineration or used as a supplemental fuel in boilers.

Buser investigated the formation of PCDD's and PCDF's from the pyrolysis of chlorobenzenes.[34] The formation mechanism included a chlorophenol and a polychlorinated diphenyl ester (PCDPE) intermediate. Chlorobenzenes are used in solvents, dyes, pharmaceuticals, and rubber production. These products make up much of the organic chlorine found in feed of municipal waste incinerators. The associated waste product may also be disposed of in an incinerator or boiler.

Buser also investigated the formation of PCDF's from the pyrolysis of PCB's.[34,35,36] No experimental work has been identified on PCDD formation from PCB's. However, studies have been identified that found PCDD's emitted from PCB fires.[60,158] In addition, PCB's are often in solution with hexachlorobenzenes that have been shown to form PCDD's. Up until 1975, PCB's were used as dielectric fluids in transformers and capacitors. PCB's have also been used in hydraulic fluids, plasticizers, and dyes. The incineration of PCB's at waste disposal facilities or in boilers may result in PCDD and PCDF emissions.

3.3.2.3 Chlorine in Feed. The chlorine content of fuel is obviously an important parameter affecting the formation of PCDD's or PCDF's. Shih *et al*. developed a ranked priority list of conventional combustion systems emitting polycyclic organic matter including PCDD's and PCDF's.[211] The rationale presented for source ranking is based on fuel characteristics and combustion conditions. Shih's work places great emphasis on both the chlorine content of the feed and the concentration of aromatics in the feed.

Other authors have demonstrated the effect of chlorine on PCDD emissions. Mahle *et al*. demonstrated that PCDD's were emitted from coal combustion only when chlorine was added.[149] Tiernan *et al*. found PCDD formation during the combustion of pine in the presence of HCl, but no PCDD's were detected during the combustion of pine alone.[226] Liberti studied the combustion of vegetables.[145] When inorganic chlorine or PVC were added to the vegetables and the mixture burned, PCDD's and PCDF's were detected in the ash.

While the precursor theory has received widespread acceptance, these inorganic chlorine studies demonstrate that the specific mechanisms involved in PCDD formation are complex and not well understood. However, it can be generally stated that chlorine must be present for the formation of PCDD, and general trends indicate that increased chlorine concentrations in the feed improve the possibilities of PCDD emissions.

3.3.2.4 Combustion Conditions. The remaining factors identified in the literature that affect PCDD emissions are combustion conditions. These include combustion temperature, residence time, supplemental fuel, fuel processing, and oxygen availability. Combustion efficiency is a function of all of these factors. In order to destroy PCDD's or prevent their formation, the combustion efficiency must be high. This requires a combination of high temperatures, available oxygen, high heating value fuel, and long mixing times.

3.3.2.5 Combustion Temperature. Experimental evidence suggests that temperatures of 500-800°C promote PCDD formation, while temperatures greater than 800°C destroy PCDD's.[6,37,62] Buser *et al*. showed that PCB pyrolysis at 550 to 650°C forms PCDF.[192] However, pyrolysis at a temperature greater than 700°C causes 99 percent destruction of PCB's and no PCDF formation. Ahling *et al*. produced similar results for both PCDD's and PCDF's during the combustion of chlorophenols.[7]

Several other studies have also been identified that demonstrate the effects of high combustion temperatures on PCDD's and PCDD precursors.[3,184,234] For example, PCDD's were not detected in the emissions of the Vulcanus incinerator ship during the combustion of PCDD-contaminated Herbicide Orange.[3] The combustion temperature during this study was 1600°C.

Combustion temperature is a function of the heating value of the fuel or supplemental fuel, the available air, and the degree of fuel processing. Two examples of combustion sources whose PCDD combustion efficiencies differ because of operating/design differences are municipal waste incinerators and hazardous waste incinerators. Municipal waste incinerators are considered a major combustion source of PCDD's.[228] The large mass burn units are characterized by low combustion temperatures. This is due in part to high moisture, low heating value fuel; poor air/feed mixing as a result of a lack of feed processing; and lack of supplemental fuel. By comparison, many hazardous waste incinerators and high efficiency boilers are designed for efficient combustion and thus have high PCDD combustion efficiencies (e.g. the Vulcanus incinerator ship[3]). These units burn high heating value fuels or add high heating value supplemental fuels, and even if the air/fuel ratio is low, the air/fuel mixing is efficient. Typically, the fuels are processed to decrease moisture and improve mixing. In many cases, high temperature afterburners are used for the combustion of offgases which increases combustion efficiency.

3.3.2.6 Residence Time. The residence time necessary to destroy PCDD's and the combustion temperature are inversely related. The higher the combustion temperature, the shorter the required residence time for PCDD destruction. Likewise, a low temperature source will require a long residence time for destruction of PCDD's. Sachdev _et al_. showed that an increase in both temperature and residence time decreased the formation of PCDD's from chlorophenol combustion.[200] Similar results have been found at hazardous waste incinerators that run with 1.5 to 2.0 second residence times. Combustion sources with longer residence times and high temperatures are less likely to form products of incomplete combustion, such as PCDD's.

3.3.2.7 _Oxygen Availability_. Oxygen availability is a function of both the air/fuel ratio and air/fuel mixing efficiency, both of which are of concern when burning solid fuels. Solid fuels and high viscosity liquid fuels such as waste tars burn as particulates or large droplets; therefore, portions of the fuel are burned in low oxygen or pyrolysis conditions. An insufficient supply of oxygen or poor air/fuel mixing will promote poor combustion conditions and PCDD formation. Jansson demonstrated that an insufficient air supply increases PCDD emissions from chlorophenol combustion.[111] Municipal waste incinerators are usually fired with excess air. However, large mass burn units may have poor air/fuel mixing due to the lack of fuel processing or poorly designed air distribution systems. Activated carbon regeneration and wire reclamation incinerators are both designed to be operated with low excess air. All of these cases have been shown to emit CDD's.[100,102,103]

3.3.2.8 _Feed Processing_. The feed material for a combustion source may be a liquid, a solid, or a gas. Both liquid and gas fuels can be easily mixed with air resulting in a high combustion efficiency; solid feeds usually require some processing to improve combustion. Often solid feeds require drying, shredding, or separation to improve combustion. Similarly, high viscosity fuels (i.e., waste tars) require preparations such as preheating and atomization prior to combustion.

Feed processing will determine in part both oxygen availability and residence time. Fine, homogeneous feed particles will improve air/fuel mixing and combustion. Larger particles will require longer residence times and may result in local oxygen deficiencies due to poor mixing. High moisture will also decrease combustion efficiency. Therefore, highly processed homogeneous feeds are less likely to emit products of incomplete combustion, such as PCDD's.

3.3.2.9 Supplemental Fuel. When a low Btu fuel is burned, the addition of supplemental fuel will increase the combustion temperature and improve combustion. Haile *et al*. tested a boiler co-firing RDF with coal.[92] The boiler temperature was 1200°C, and no PCDD's were detected. Dow Chemical tested an industrial incinerator burning waste tars without supplemental fuel and found ppb levels of TCDD's in the fly ash.[62] After the addition of a supplemental fuel, no TCDD's were detected.

CHAPTER 4

TEST PROGRAM DEVELOPMENT:
SOURCE CATEGORY RANKING AND TEST SITE SELECTION PROCEDURES

This chapter describes the procedures used to select the combustion source categories and the specific facilities tested under the Tier 4 emissions testing program. These procedures were designed to address the question, "What combustion sources emit CDD's?" The Tier 4 budget restricted the ability to answer this question thoroughly, in that it financially limited both the number of source categories and the number of sites within each source category that could be tested. It was not possible to select a statistically valid, representative sample of combustion sources given the limited number of tests that could be performed. The decision was made to select source categories with a high probability of having CDD emissions, i.e. "worst case."

The sections that follow discuss 1) which source categories were selected for testing, 2) the criteria used to rank source categories in terms of potential for CDD emissions, 3) the ranking assigned each source category, and 4) the procedure used to select emissions test sites.

The source category and site selection tasks evolved as the program progressed. New source categories such as drum reclamation furnaces, blast furnaces, and industrial incinerators were added at various times in the stack testing program. Similarly, charcoal manufacturing operations and PCP sludge incinerators that were initially considered for stack testing were dropped from the program as additional information was gathered.

The ash sampling and analysis program was originally envisaged to be an integral part of the source category ranking and site selection process. Unfortunately, PCDD/PCDF analyses of the ash samples could not be conducted quickly enough to serve in the ranking and site selection process. However, results of ash analysis for some source categories reported by other agencies played a part in site selection as, for example, in the inclusion of a secondary metals blast furnace in the test program.

4.1 SOURCE CATEGORY SELECTION AND RANKING

This section discusses the approach used to select and rank combustion source categories for the Tier 4 emission test program. The initial ranked list of source categories is presented, and modifications that were made to this list are discussed. Details on the rationale used in ranking the various sources are also provided.

4.1.1 Development of Ranked Source Category List

4.1.1.1 Preliminary Ranked Source Category List. The Initial Tier 4 Literature Review provided information on 1) previous CDD emissions studies, and 2) experimental studies of CDD formation mechanisms. This review produced a list of 13 broadly defined source categories for which some CDD emissions data had been collected (see Section 3.2). Based on a review of the emissions data and experimental studies done, the initial review hypothesized that the following factors affect CDD emissions from combustion sources:

1. PCDD in the feed,
2. PCDD precursors in the feed (chlorophenols, chlorobenzenes, PCB's),
3. total chlorine in the feed,
4. combustion conditions (temperature, residence time, and oxygen availability),
5. feed processing, and
6. supplemental fuel.

The general method used to select the combustion source categories tested, and the number of facilities to be tested in each category is outlined in Figure 4-1. Based on information contained in the field test reports and experimental studies reported in the literature, a list of combustion source categories believed to have the greatest potential to emit CDD's was developed. This list was modified to a ranked list, in which source categories were grouped according to their estimated potential to emit CDD's. The three main criteria used to rank, or group, the sources were source

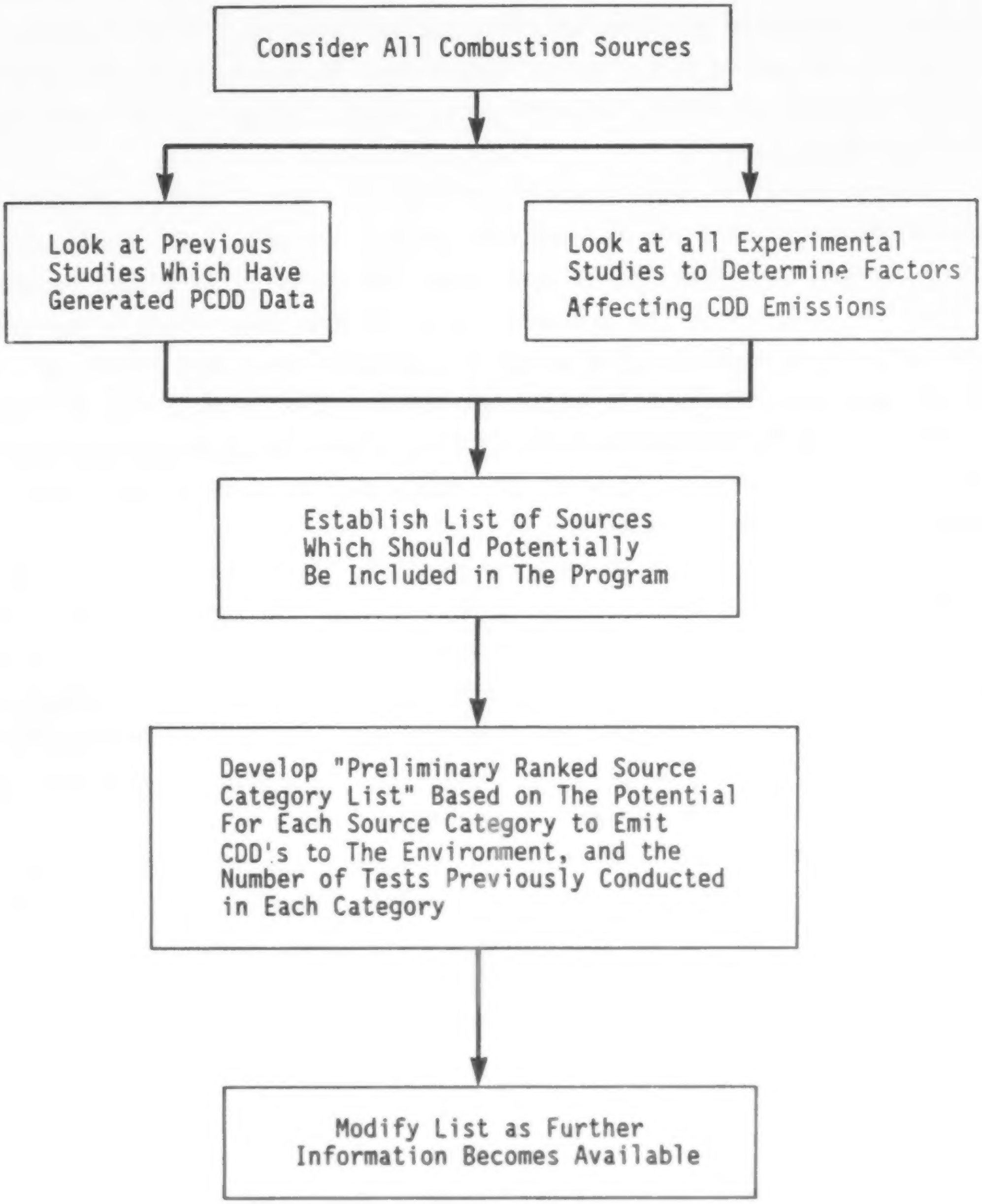

Consider All Combustion Sources
Look at Previous Studies Which Have Generated PCDD Data
Look at all Experimental Studies to Determine Factors Affecting CDD Emissions
Establish List of Sources Which Should Potentially Be Included in The Program
Develop "Preliminary Ranked Source Category List" Based on The Potential For Each Source Category to Emit CDD's to The Environment, and the Number of Tests Previously Conducted in Each Category
Modify List as Further Information Becomes Available

FIGURE 4-1. DEVELOPMENT OF RANKED SOURCE CATEGORY LIST.

category size, precursor level in the feed, and the number of valid tests previously conducted at sites within a source category. Other factors considered were those listed above (identified by the experimental studies), and the location of facilities within the source category (i.e., the potential for human exposure).

Source categories were ranked A through D. Rank A source categories were expected to emit CDD's and to have the greatest potential for human exposure. Rank B sources were expected to have lower CDD emission potential based on the size of the category or the precursor level in the feed. Rank C sources were expected to have even less CDD emission potential than Rank B sources. Rank D sources were considered to be adequately tested for the purposes of Tier 4. The Preliminary Ranked Source Category List (from the Initial Literature Review, October 1984), along with the description of each of the ranking categories, is shown in Table 4-1.

4.1.1.2 Modification of Preliminary List. Over the course of the stack emissions testing program, the preliminary ranked list was modified as a result of both 1) the inputs received from national, regional, state and local agencies, and 2) further study of each of the combustion source categories. A few source categories were shifted from one rank to another, while other source categories not identified in the Initial Literature Review were added to the list. The source categories that experienced a change in ranking were PCP sludge incinerators, industrial incinerators, charcoal manufacturers and wood-fired boilers. Those categories that were added to the list for the first time were drum and barrel reclamation furnaces, secondary metal recovery furnaces and hospital waste incinerators. Table 4-2 summarizes the changes made from the preliminary list, and the reasons for these changes.

4.1.1.3 Final Ranked List. The final ranked list of source categories (as used for the testing program) is shown in Table 4-3. The objective of the testing program was to test Rank A sources three times each, Rank B sources once each, and as many Rank C sources as possible. The categories that were tested are indicated in Table 4-3. The rationale for the ranking assigned to each source category is discussed in the next section.

TABLE 4-1. PRELIMINARY RANKED SOURCE CATEGORY LIST (October 1984)

Rank A Source Categories

Sewage Sludge Incinerators
Black Liquor Boilers

Rank B Source Categories

PCP Sludge Incinerators
Carbon Regeneration (Industrial)
Charcoal Manufacturing
Wire Reclamation Incinerators

Rank C Source Categories

Commercial Boilers Firing Fuels Contaminated with Chlorinated Organic Wastes
Woodstoves
Wood Boilers (Firing PCP-Treated Wood)
Mobile Sources
Small Spreader-Stoker Coal Boilers
Hazardous Waste Incinerators
Lime/Cement Kilns Cofired with Chlorinated Organic Wastes
Industrial Incinerators
Open Burning (Agricultural)
Apartment House Incinerators
Other Sources Recommended by State and Regional Offices (e.g., landfill flares, forest fires)

Rank D Source Categories

Municipal Solid Waste (MSW) Incineration
Industrial Boilers Cofiring Wastes

Rank A - Large source categories (greater than 1 million tons of fuel and/or waste burned annually) with elevated dioxin precursor contamination of feed/fuel. These categories are judged to have the highest potential to emit TCDD.
Rank B - Small source categories (less than 1 million tons of fuel and/or waste burned annually) or source categories with limited dioxin precursor contamination of feed/fuel. These categories have a high potential to emit TCDD.
Rank C - Source categories less likely to emit TCDD.
Rank D - Source categories that have already been tested three or more times.

SOURCE: Initial Literature Review

TABLE 4-2. MODIFICATION OF PRELIMINARY LIST

Source Category	Modification	Reason for Modification
PCP Sludge Incinerators	Rank B to Rank C	No longer practiced. This sludge is being incinerated in hazardous waste incinerators.
Industrial Incinerators	Rank C to Rank B	Many units operating in the U.S. Potential high level of chlorinated plastics in the feed.
Charcoal Manufacturing Operations	Rank B to Rank C	PCP-treated wood is not used to a large extent in this source category.
Wood-fired Boilers	Rank C to Rank B	Very large source cateogy. Some units burn wood stored in salt water (i.e., wood contains Cl^-).
Drum and Barrel Reclamation Furnaces	Add as Rank B	Over 100 facilities in U.S. Precursor levels may be high. Poor combustion conditions.
Secondary Metal Recovery Furnaces	Add as Rank B	Chlorinated plastics often present in the feed. PCDD detected in baghouse catch.
Hospital Waste Incinerators	Add as Rank C	Burning chlorinated plastics.

TABLE 4-3. FINAL RANKED SOURCE CATEGORY LIST

Rank A	Sewage Sludge Incinerators (3)
	Black Liquor Boilers (3)
Rank B	Industrial Incinerators (1)
	Wire Reclamation Incinerators (1)
	Carbon Regeneration Furnaces (1)
	Secondary Metal Blast Furnaces (1)
	Wood-Fired Boilers (1)
	Drum and Barrel Reclamation Furnaces (1)
Rank C	Mobile Sources[a] (1)
	Wood Stoves[a] (1)
	Spreader-Stoker Coal Fired Boilers
	Commercial Boilers Burning Chlorinated Organic Wastes
	Lime Kilns
	Cement Kilns
	Hazardous Waste Incinerators
	Hospital Waste Incinerators
	Apartment House Incinerators
	Charcoal Manufacturing Operations
	Open Burning
Rank D	Municipal Waste Incinerators
	Commercial Waste Boilers

(3) Indicates that the source category was tested three times under Tier 4.

(1) Indicates that the source category was tested once under Tier 4.

[a] Indicates that the source category was tested once under Tier 4 in conjunction with another test program.

4.1.2 Rationale for the Source Category Ranking

4.1.2.1 Rank A Sources. The two Rank A source categories are sewage sludge incinerators and black liquor boilers. Three Tier 4 source tests were performed in each of these categories.

There are over 200 sewage sludge incinerators operating in the United States. Most sludge incinerators are large units (burning several tons/hr) and many operate 24 hrs/day. There is a potential for the feed to contain CDD precursors at some facilities, especially where the wastewater influent contains significant input from the industrial sector. Some plants receive as much as 60 percent industrial flow.[108a] Precursors (chlorophenols, chlorobenzenes, and PCB's) have been found in parts-per-million (ppm) concentrations in the wastewater and/or sludge at some facilities. Some sludges also contain several hundred ppm of inorganic chlorine. Additionally, combustion conditions in these incinerators would tend to promote CDD formation. The feed characteristics can vary widely and maximum furnace temperatures are typically 700-800°C. In an earlier Canadian study, PCDD's were detected in stack emissions.[23]

The black liquor boiler source category is similar to sewage sludge incineration in that both have numerous large units burning material capable of forming CDD's. Approximately 42 million tons of black liquor are burned in boilers annually.[105] Initially, it was felt that the chief sources of precursors in the black liquor circuit would be PCP-treated wood, biocides used in the pulping operation, or wood stored in salt water; however, the primary source of chlorine in the black liquor at many facilities is spent acid from ClO_2 generation systems. The spent acids are added to the black liquor circuit as a source of make-up sodium and sulfur. An alternate significant source is makeup water. Black liquor chlorine contents are as high as 2 to 3 percent by weight for some plants. No previous CDD emission tests have been performed in the black liquor boiler source category.

4.1.2.2 Rank B Sources. Six source categories ultimately ended up as Rank B sources: industrial incinerators, wire reclamation incinerators, carbon regeneration furnaces, secondary metal blast furnaces, wood-fired boilers, and drum and barrel reclamation furnaces. One emissions test was performed in each of these source categories.

Thousands of batch-fed solid waste industrial incinerators have been installed in the last ten years. While the feed to these units is highly site-specific, some feed streams contain plastics, PCP-treated wood, and other materials that may contain chlorinated-organics. Most units have multiple combustion chambers, the first of which is a "starved-air" chamber which could be conducive to CDD formation. Trace amounts of CDD were found in the only previous test of an industrial incinerator.[41]

The size and general practices of the wire reclamation incineration source category are largely undefined. Many facilities have switched from incineration to wire chopping as a means of reclaiming the metal in the wire. Of those facilities still incinerating wire, many do not have state permits (according to state agencies) and/or do not belong to the industry trade organizations, such as the National Association of Recycling Industries or the Wire Association International. Therefore, information is limited. Most wire reclamation incinerators currently in use are dual chambered, with a starved air combustion chamber and a gas-fired afterburner chamber. The major precursors being burned are polyvinylchloride (PVC) in wire coatings, and PCB's in transformers. Industry and trade organization contacts indicated that the burning of PVC-coated wire is discouraged; however, this wire continues to comprise at least a small fraction of the total feed to most wire incinerators. In previous tests, parts-per-trillion (ppt) levels of TCDD's were detected in stack scrapings.[103]

There are few furnaces regenerating industrial carbon operating in the United States. Those facilities that regenerate carbon used to treat industrial waste streams (especially for industries handling CDD precursors) have a high potential for CDD emissions. This is due to the low air/fuel ratio and the low combustion temperatures, and also the heterogeneity of the waste streams treated by the carbon. PCDD was found at ppt levels in previous analyses of furnace fly ash samples. The carbon regenerated in these tests had been used to treat a municipal water supply, and contained precursor levels far below what would be found in carbon used to treat many industrial streams.[102]

The secondary copper subcategory of the secondary metal blast furnace source category is also small. The operating facilities have a good potential for CDD emissions based on feed materials and combustion conditions. The feed to these furnaces is made up of different types of metallic scrap, and typically contains significant amounts of plastic-bearing materials (i.e., PVC-coated wire, telephone scrap, etc.). Combustion conditions are poor, since scrap is charged on a batch basis. Feed/air mixing tends to be poor, and the temperatures throughout the furnace vary.

Approximately 60 million tons of wood are burned annually in wood-fired boilers in the United States. This was the largest source category tested in terms of the amount of material burned. Some facilities in the Pacific Northwest store wood in salt water prior to combustion in the boilers. Thus, feed to wood-fired boilers can contain several weight percent of inorganic chlorine. However, the organic chlorine content of the wood burned is expected to be very low. No facilities were identified that regularly burn wood that has been treated with pentachlorophenol or other chlorinated organics.

The drum and barrel reclamation furnace source category is made up of approximately 250 facilities nationwide that recondition drums by burning and/or washing processes. Over 14 million drums are processed annually using drum reclamation furances. The amount of waste residue removed by burning has been estimated at 35,000 tons annually, making this a fairly small source category. The material being burned however, can contain most different kinds of wastes, including chlorinated organics. Some facilities burn drums containing wastes generated during pesticide manufacturing. Additionally, many drums are coated with phenolic resins. Most furnaces are equipped with afterburners. Temperature in the furnaces average 650°C (1,200°F), while afterburners achieve average temperatures of approximately 750°C (1,380°F). Residence times of less than one second in the combustion zone are common for this industry.

4.1.2.3 Rank C Sources. The Rank C source categories are as follows: mobile sources, woodstoves, small spreader stoker coal-fired boilers, commercial boilers burning chlorinated organic wastes, PCP sludge incinerators, lime kilns, cement kilns, hazardous waste incinerators, hospital waste incinerators, apartment house incinerators, charcoal manufacturing operations and open burning. With the exception of mobile sources and woodstoves, these sources were excluded from the stack testing program for one or more of the following reasons:

1. Minimal CDD precursors present in the feed.
2. Source category believed to be no longer existent or considerably different from what it was when identified in the Initial Literature Review.
3. High combustion temperatures and destruction efficiencies required by law indicate low potential for CDD emissions.
4. Insufficient budget to test all source categories of interest.

It should be noted that both mobile sources and woodstoves were sampled for CDD emissions through other on-going testing programs.

4.1.2.4 Rank D Sources. The Rank D source categories are municipal waste incinerators and commercial waste boilers. Several CDD emission tests have been performed in each of these categories. The categories were considered to be adequately tested for the purpose of Tier 4. Data from the previous tests have been incorporated into the literature review (Chapter 3). Where high quality, complete stack tests are available for these sources, the data have been incorporated in the Tier 4 data analyses (Chapters 5 and 6).

4.2 TEST SITE SELECTION

4.2.1 Background

The objective of the test program was to focus the testing efforts on the source categories believed to have the greatest potential for CDD emissions. Therefore, Rank A sources were tested three times each, Rank B sources were tested once each, and Rank C sources were tested only when testing could be done easily in conjunction with other programs. In the Initial Literature Review, it was stated that the results of the Ash Sampling Program analyses would probably be used to determine which of the Rank B and C categories would be emission tested; however, these results were unavailable until later in the program. Ultimately, the final ranked list (Table 4-3) was used as the basis for selecting which source categories would be tested, and the extent to which each category would be tested.

The differences in the extent of testing desired for each source category dictated that a different approach be taken toward site selection for each category. For source categories where only one test would be conducted, a facility was chosen that was considered to have a greater potential for CDD emissions than most others in that source category (these were termed "high potential" facilities). This selection was based upon a qualitative assessment of source characteristics and factors affecting PCDD/PCDF emissions. This is described in more detail below. At least one "high potential" facility was chosen for each Rank A source category. Other Rank A sites chosen were believed to possess average or above average CDD emission potential, as compared to other sources in that category. These facilities were referred to as "average potential" or "average/high potential" sites, respectively.

A major part of the site selection process was, therefore, source category characterization. The following variables were examined in each source category:

1. average size of combustion units,
2. range of combustion unit sizes in source category,
3. subcategories of combustion units (e.g., multiple hearth or fluidized bed for sewage sludge incinerators),
4. precursor levels and other feed stream characteristics,
5. supplemental fuel usage,
6. normal combustion unit operating characteristics (% O_2, temperatures, feed/air mixing, operating schedules),
7. control device types, and
8. control device design and operation.

This information was used to subjectively rank the sources within a source category by the potential to emit CDD and, therefore, determine which facilities would be tested. Due to time constraints, only information that was readily available was obtained.

4.2.2 Site Selection Methodology

The general approach used in selecting test sites is shown schematically in Figure 4-2. Specific site selection procedures for each source category will be briefly discussed in Section 4.2.3.

The initial step taken was to develop a list of facilities within a source category. The next step, often taken concurrently with the first, was to characterize the source category in terms of the variables listed in the previous section (4.2.1). Then, site-specific information was gathered on units within the source category. Of primary interest was the level of CDD precursors in the feed to these units. Site-specific information came primarily from the following sources:

1. recommendations from federal, state and local environmental agencies,
2. previous studies of specific facilities, and
3. industry trade organization contacts.

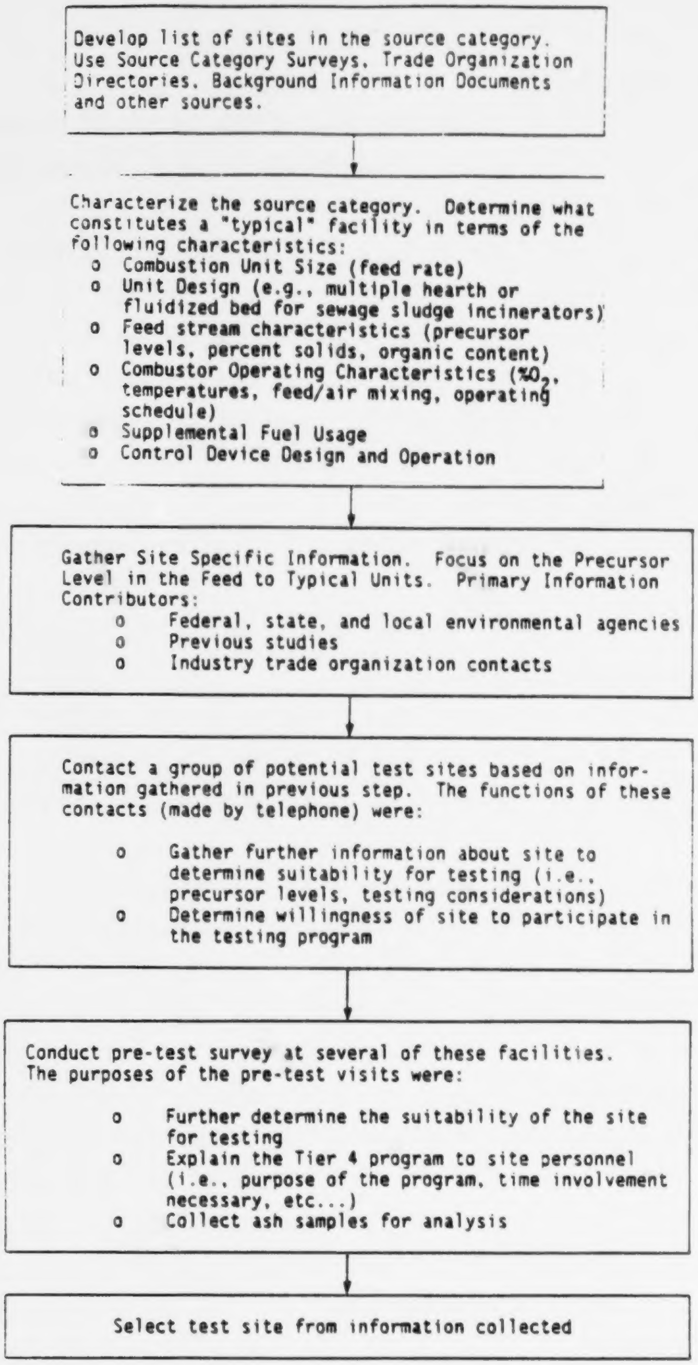
Selected facilities were contacted by telephone to confirm the information gathered about the site, to determine their willingness to participate in the Tier 4 test program, and to discuss factors which would affect sampling.

The last step taken, prior to selecting a site for testing was to conduct a pre-test survey. Pre-test surveys were conducted at several of the facilities telephoned (typically three pre-tests were conducted for every test site selected). The functions of each pre-test survey were as follows:

1. To determine if a site was suitable for the Tier 4 testing program. Precursor information, combustion conditions, and sampling locations were examined to estimate both the approximate potential for CDD emissions and the ease with which the facility could be sampled.
2. To explain the Tier 4 program to site personnel (i.e., the purpose of the program, the time involvement necessary, etc.).
3. To collect ash samples for analysis.

4.2.3 Test Sites Selected

Test sites were selected based on the information gathered during pre-test survey visits. A summary of the information collected at all tested and pre-tested sites is presented in this section.



Develop list of sites in the source category. Use Source Category Surveys, Trade Organization Directories, Background Information Documents and other sources.

Characterize the source category. Determine what constitutes a "typical" facility in terms of the following characteristics:

- Combustion Unit Size (feed rate)
- Unit Design (e.g., multiple hearth or fluidized bed for sewage sludge incinerators)
- Feed stream characteristics (precursor levels, percent solids, organic content)
- Combustor Operating Characteristics (%O_2, temperatures, feed/air mixing, operating schedule)
- Supplemental Fuel Usage
- Control Device Design and Operation

Gather Site Specific Information. Focus on the Precursor Level in the Feed to Typical Units. Primary Information Contributors:

- Federal, state, and local environmental agencies
- Previous studies
- Industry trade organization contacts

Contact a group of potential test sites based on information gathered in previous step. The functions of these contacts (made by telephone) were:

- Gather further information about site to determine suitability for testing (i.e., precursor levels, testing considerations)
- Determine willingness of site to participate in the testing program

Conduct pre-test survey at several of these facilities. The purposes of the pre-test visits were:

- Further determine the suitability of the site for testing
- Explain the Tier 4 program to site personnel (i.e., purpose of the program, time involvement necessary, etc...)
- Collect ash samples for analysis

Select test site from information collected

FIGURE 4-2. PROCEDURES USED FOR SELECTING A GENERIC TEST SITE.

4.2.3.1 Sewage Sludge Incinerators. For the Tier 4 program, pre-test surveys were conducted at 11 sewage sludge incinerators. Of these, three were selected for testing (Sites SSI-A, SSI-B, and SSI-C). Two of the test facilities were judged to have "average" potential for CDD emissions with respect to other sludge incinerators. The third test site was judged to be a "high potential" site based upon consideration of the factors affecting PCDD/PCDF emissions.

The characteristics of the pre-tested facilities are summarized in Table 4-4. The common unit type was a multiple hearth furnace controlled by a scrubber system. Typical precursor levels were ppm or parts per billion (ppb) levels of various chlorinated organics. Combustion temperatures were in the 500 to 800°C (930 to 1,470°F) range.

4.2.3.2 Black Liquor Boilers. Six black liquor boilers were pre-test surveyed. Three facilities were chosen for Tier 4 testing (Sites SSI-A, SSI-B, and SSI-C). The CDD emissions potential of the test sites ranged from "average" to "high." This potential was based on the the amount of chlorine found in the feed to these units.

Pre-test facility characteristics are shown in Table 4-5. There were several major differences among the units including the boiler manufacturer, the evaporation technique employed, and the source of the make-up chemical used. All units were controlled by electrostatic precipitators. Sources of chlorine in the black liquor include ClO_2 generation waste acids that are added to the black liquor as make-up chemical, salt in the wood chips used in the pulping process (resulting from salt-water storage of wood), and chloride contained in the ground water that is ultimately used as makeup in the black liquor circuit.

4.2.3.3 Industrial Incinerators. Only one industrial incinerator site was pre-test surveyed, and this site was subsequently tested. The site was identified by the state and regional EPA offices as a good candidate for the program because of the high precursor concentration in the feed, and the site's willingness to participate. The applicability of this source category for the Tier 4 program was explored and subsequently confirmed in several

TABLE 4-4. INFORMATION COLLECTED AT SEWAGE SLUDGE INCINERATOR SITES DURING PRE-TEST SURVEYS FOR TIER 4

Site Code	SS1-A	SS1-B	SS1-C	SS1-D	SS1-E	SS1-F	SS1-G	SS1-H	SS1-I	SS1-K	SS1-L
Test Site	X	X	X								
Estimated Dioxin Emissions Potential	Avg	Avg/ High	High	Avg	Avg/High	High	Avg/ High	Avg/ High	High	Avg	Low
Unit Design	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
Feed Rate (tons/hr on a wet basis)	3.75	2.9 (dry)	12	5		Variable	3			7.5	3
Control Device	WSCR	WSCR	WSCR	WSCR	WSCR	WSCR	WSCR	WSCR	WSCR	WSCR	WSCR
Precursor Information	0.13 ppm PCB's 0.02 ppm Cl^- benz	0.03 ppm Cl^- benz	0.003 ppm Cl^- benz	25% Industrial Contribution	30% Industrial Contribution	5-10 ppm PCB's 40-60% Industrial Contribution	20% Industrial Contribution	20% Industrial Contribution		6% Industrial Contribution	Low
Maximum Temp. in Incinerator (°F)	1400	1600	1400		1500	1500				1500	
Incinerator Outlet Temp. (°F)	800	1150	1000			660				850	

Terminology: Avg - Average
Cl^- benz - Chlorinated benzenes
MH - Multiple hearth furnace
PCB's - Polychlorinated biphenyls
WSCR - Wet scrubber

TABLE 4-5. INFORMATION COLLECTED AT BLACK LIQUOR BOILER SITES DURING PRE-TEST SURVEYS FOR TIER 4

Site Code	BLB-A	BLB-B	BLB-C	BLB-D	BLB-F	BLB-H
Test Site	X	X	X			
Estimated Dioxin Emissions Potential	Avg/ High	High	Avg	High	Avg	Low
Feed Rate (lbs/hr)	120,000	100,000	300,000	-	360,000	-
Chlorine Content in the Feed (%)	.5 (dry)	3.5 (dry)	.3 (dry)	1.3 (dry)	.2 (dry)	(Expected to be negligible)
Source of Chlorine in the Feed	Saltcake from ClO_2 generator	Saltcake from ClO_2 generator	Logs stored in in salt water			No known source
Control Device	Wet bottom ESP	Dry ESP	Dry ESP	Dry ESP/scrubber	ESP	-
Percentage Oxygen in Boiler (%)	6	3-4	2-3	5	2-3	-
Control Inlet Temperature (°F)	600		315	300-350	350-400	-

Terminology: ESP - Electrostatic precipitator reports.[40,41] The characteristics of the facility (Site ISW-A) tested are summarized in Table 4-6.

4.2.3.4 Wire Reclamation Incinerators. Three wire reclamation incinerators were pre-test surveyed, and one facility was chosen for testing (Site WRI-A). The facility chosen was judged to be a "high" potential site because the feed contained some PVC-coated wire and PCB-contaminated transformer cores.

Pre-test facility characteristics are shown in Table 4-7. The typical wire incinerator is a batch-fed, natural gas-fired unit equipped with an afterburner for emissions control. The EPA's authority under Section 114 of the Clean Air Act was used to gain entrance to two of the pre-tested facilities in the wire reclamation source category.

4.2.3.5 Carbon Regeneration Furnaces. A single site was pre-test surveyed and eventually tested. This site was chosen because it was felt to be representative of other facilities in the source category. The facility was judged to have "average/high" potential for CDD emissions based on the heterogeneity of the feed stream, and the potential for precursors to be present. A summary of the characteristics of the facility tested is given in Table 4-8.

4.2.3.6 Secondary Copper Blast Furnaces. Two blast furnaces were pre-tested, and one was chosen for testing. The facility chosen was estimated to have "high" potential for CDD emissions due to the abundance of chlorinated plastics in the feed. The other facility processes little plastic-bearing copper scrap in its blast furnace and was judged to have "low" potential for CDD emission. Characteristics of the pre-tested facilities are given in Table 4-9.

4.2.3.7 Wood-Fired Boilers. Four wood-fired boilers were pre-tested. One site was chosen for testing. This facility was judged to have "high" potential for CDD emissions with respect to the rest of the source category because it fires wood which has been stored in salt water (i.e., salt-laden wood. The inorganic chlorine content in the feed to this unit is high. The other facilities pre-tested also reported using some salt-laden wood, but to a lesser degree than the site chosen for testing.

TABLE 4-6. INFORMATION COLLECTED AT THE INDUSTRIAL INCINERATOR TEST SITE DURING THE PRE-TEST SURVEY

Site Code	ISW-A
Estimated Dioxin Emissions Potential	High
Unit Design	Dual Chamber Controlled-Air Incinerator
Feed Rate	2300 lb/hr
Control Device	Afterburner
Feed Material/ Precursor Information	Wood scraps, Plastic (polyvinyl chloride), Paint Sludge
Maximum Furnace Temperature	1800°F

TABLE 4-7. INFORMATION COLLECTED AT WIRE RECLAMATION INCINERATOR SITES DURING PRE-TEST SURVEYS FOR TIER 4

Site Code	WRI-A	WRI-B	WRI-C
Test Site	X		
Estimated Dioxin Emissions Potential	High	Avg/ High	Avg/ High
Unit Design	Dual-chambered, batch-fed	Proprietary	Dual-chambered batch-fed
Feed Rate (lb/hr)	800	-	-
Control Device	Afterburner	Afterburner/ baghouse	Afterburner
Feed Material/ Precursor Information	Wire, Transformers	Wire, other metal scrap	Wire, other metal scrap
Incinerator Temperature (°F)	1000	-	-
Afterburner Temperature (°F)	1900	-	1600-1700

TABLE 4-8. INFORMATION COLLECTED AT THE CARBON REGENERATION FURNACE TEST SITE DURING THE PRE-TEST

Site Code	CRF-A
Estimated Dioxin Emissions Potential	High
Unit Design	Multiple Hearth
Feed Rate	63,000 lb/day
Control Device	Afterburner, spray cooler, baghouse
Feed Material/ Precursor Information	Spent carbon potentially containing chlorobenzenes and other chlorinated organics
Maximum Gas Temperature	1800°F

TABLE 4-9. INFORMATION COLLECTED AT SECONDARY COPPER BLAST FURNACE SITES DURING PRE-TEST SURVEYS FOR TIER 4

Site Code	MET-A	MET-B
Test Site	X	
Estimated Dioxin Emissions Potential	High	Low
Feed Rate	2400 tons/day	200 tons/day
Control Device	Baghouse	Baghouse
Feed Material/ Precursor Information	Plastic-bearing copper scrap, coke	Non-plastic-bearing copper scrap, metallurgical slags, coke
Maximum Temperature (^{o}F)	1500	-

The characteristics of the pre-tested facilities are summarized in Table 4-10. All of these used Dutch oven "hogged-fuel" boilers. The common control device used for these units is a baghouse.

4.2.3.8 Drum and Barrel Reclamation Furnaces. Four drum and barrel reclamation facilities were visited and one was chosen for testing. The testing, and some of the pre-test surveys, were conducted under authority of Section 114 of the Clean Air Act. As is noted in the table, a change was made in the code for the sites between the site selection process and the source testing. The site labeled DBR-A was the subject of testing.

A summary of the information collected during pre-tests is given in Table 4-11. All facilities used a continuous-feed conveyor furnace equipped with natural gas-fired burners and an afterburner. Precursor levels were expected to be significant at all facilities pretested.

4.3 SUMMARY DESCRIPTION OF ALL TEST SITES

A brief summary description of the 13 test sites in terms of manufacturer, feed rate and control device is given in Table 4-12. Further site specific design and operating data are contained in the individual site test reports.

TABLE 4-10. INFORMATION COLLECTED AT WOOD-FIRED BOILER SITES DURING PRE-TEST SURVEYS FOR TIER 4

Site Code	WFB-A	WFB-B	WFB-C	WFB-I
Test Site	X			
Estimated Dioxin Emissions Potential	High	High	High	High
Unit Design	Dutch oven	Dutch oven	Dutch oven	Dutch oven
Feed Rate (lb/hr)	45,000	175,000	50,000	-
Control Device	Cyclone/ Baghouse	Multiclone/ Electrostatic gravel bed	Baghouse	-
Feed Material/ Precursor Information	Hogged-fuel, primarily salt-laden wood	Hogged-fuel, some salt-laden wood	Hogged-fuel, some salt-laden wood	Hogged-fuel, some salt-laden wood
Maximum Temp. in Boiler (°F)	1800	2300-2600	-	-

TABLE 4-11. INFORMATION COLLECTED AT DRUM AND BARREL RECLAMATION FURNACE SITES DURING PRE-TEST SURVEYS FOR TIER 4

Site Code	DBR-A*	DBI-A	DBI-C	DBI-F
Test Site	X			
Estimated Dioxin Emissions Potential	High	High	High	Avg
Unit Design	Conveyor	Conveyor	Conveyor	Conveyor
Feed Rate (drums/hr)	125	150	180	100
Source of Barrels/ industry, Chemicals, Precursor Information	Paint industry, orange juice concentrate	Textile plants, chemicals, paint industry	Chemicals, textiles, oil	Orange juice, textiles
Incinerator Temp. (^{o}F)	1000	1100	1200	1400
Afterburner Temp. (^{o}F)	1450-1600	1200-1300	1350	2600

*The pretest site code for site DBR-A was DBI-B.

TABLE 4-12. SUMMARY DESCRIPTION OF THE TIER 4 TEST SITES

SEWAGE SLUDGE INCINERATORS

SSI-A	3.75 wet TPH Envirotech six-hearth multiple hearth incinerator controlled by a cyclone followed by a venturi/impingement tray scrubber. Average industrial contribution to treatment plant influent.
SSI-B	12.5 wet TPH Envirotech nine-hearth multiple hearth incinerator controlled by a cyclone followed by a waste heat boiler, a venturi scrubber and a subcooler. Average industrial contribution to treatment plant influent. Installed in 1983.
SSI-C	13.5 wet TPH Nichols twelve-hearth multiple hearth incinerator controlled by a 3 tray impingement scrubber. High industrial contribution to treatment plant influent. Installed in 1974.

BLACK LIQUOR BOILERS

BLB-A	900 TPD low odor B&W recovery boiler controlled by a wet bottom ESP. Average chloride content in black liquor. Installed in 1983.
BLB-B	800 TPD direct contact CE recovery boiler controlled by a dry bottom ESP. High chloride content in black liquor. Installed in 1962.
BLB-C	850 TPD low odor CE recovery boiler controlled by a dry bottom ESP. Average chloride content in black liquor. Installed in 1973.

WOOD COMBUSTION

Wood Fired Boiler WFB-A	100,000 lb/hr steam B&W Dutch oven boiler controlled by a baghouse. Salt-laden wood fired in the boiler. Installed in 1939.
Woodstove WS-A	Atlanta Stove Works free-standing non-catalytic woodstove. Oak and pine were burned during the tests.
Industrial Solid Waste Incinerator ISW-A	18 MMBtu/hr Kelley Model 2500 two-chamber controlled air incinerator with an afterburner. Incinerator feed contains polyvinyl chloride and pentachlorophenol-treated wood. Installed in 1981.

TABLE 4-12. Continued.

SECONDARY METALS RECOVERY

Secondary Copper Blast Furnace MET-A	625 TPD (scrap input) rectangular shaft blast furnace with oxygen enrichment. Emissions controlled by afterburners and a baghouse system. Furnace feed contains plastic-bearing copper scrap.
Wire Reclamation Incinerator WRI-A	1200 lb/hr United Corporation Model G-466 batch feed wire reclamation incinerator controlled by a natural gas-fired afterburner. Incinerator feed consists of coated wire and/or drained transformer cores containing PCB's. Installed in 1978.

MISCELLANEOUS SOURCES

Drum and Barrel Reclamation Incinerator DBR-A (DBI-B)	150 drum/hr ECO Model 100 drum reclamation furnace controlled by a natural gas-fired afterburner. Combustible materials in feed include solvent residues and drum coatings. Drums originally contained lacquer, organic solvents, inks, enamel-type paints, etc. Installed in 1974.
Carbon Regeneration Furnace CRF-A	109,000 lb/day (bare carbon) multiple hearth furnace controlled by an afterburner, a sodium carbonate spray cooler, and a baghouse. Spent carbon feed was used for treatment of industrial wastewaters known to contain chlorinated organics. Furnace rebuilt in 1980.

CHAPTER 5
TIER 4 EMISSIONS TESTING RESULTS

The purpose of this chapter is to describe the Tier 4 emissions testing program and to summarize the results of the program. The summary of results includes data on homologue-specific CDD/CDF emissions, CDD/CDF precursor contents of combustion device feed materials, continuous monitoring of various combustion products, HCl/total chloride emissions, combustion device and control device operating conditions, and CDD/CDF contents of combustion device and control device ash samples. The CDD/CDF emissions data are presented in site-average form in this chapter, with run-specific data contained in Appendix A. Additional testing details can be obtained in the site-specific test reports that have been prepared for each site. An analysis of the test data is presented in Section 6-1 of this report.

The remainder of this chapter consists of six sections. Section 5.1 describes the overall sampling matrix. The various samples taken at each Tier 4 test site are listed. In Section 5.2, the CDD/CDF emissions data are presented, followed by the CDD/CDF precursor data in Section 5.3. The HCl emissions data and continuous monitoring data are presented in Sections 5.4 and 5.5, respectively. Process data documenting the operation of the combustion devices and the control devices during the test periods are summarized in Section 5.6. The CDD/CDF contents of ash samples taken at the Tier 4 emissions test sites are presented in Section 5.7, and in-plant ambient CDD/CDF concentration data developed for three Tier 4 test sites are presented in Section 5.8.

5.1 SAMPLING MATRIX

Table 5-1 summarizes the sampling performed at the Tier 4 emissions test sites. It should be noted that not all of the samples shown in Table 5-1 were analyzed. An analysis priority was assigned to each stream sampled. Low priority streams such as feed samples and soils were often not analyzed

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TABLE 5-1. SOURCE SAMPLING MATRIX FOR THE TIER 4 TEST PROGRAM

Site	MM5 Dioxin/Furan Sampling[a] Inlet	MM5 Dioxin/Furan Sampling[a] Outlet	HCL Sampling	Continuous Emissions Monitoring[b]	Ash Sampling	Feed Sampling[c]	Ambient Air Sampling	Soil Sampling	Auxiliary Process Sampling
01/SSI-A	Yes (2)	Yes (1)	No	All Species (inlet)	Bottom Ash (1) Scrubber Blowdown (2)	Feed Sludge (2) Fuel Oil (3)	Yes (2)	Yes (3)	No
02/ISW-A	No	Yes (1)	Yes	All Species No SO_2 (outlet)	Bottom Ash (1)	Feed Sludge (3) Fuel Oil (3)	Yes (2)	Yes (3)	No
03/SSI-B	No	Yes (1)	No	All Species No SO_2 (inlet)	Bottom Ash (1) Scrubber Blowdown: solids(1), filtrate(1)	Feed Sludge (2)	None	Yes (3)	No
04/BLB-A	Yes (1)	Yes (1)	Yes	All Species (inlet)	None	Strong Black Liquor (2)	None	Yes (3)	Yes
05/BLB-B	Yes (1)	Yes (1)	Yes	All Species (inlet)	None	Strong Black Liquor (2)	None	Yes (3)	Yes
06/WRI-A	No	Yes (1)	Yes	All Species No SO_2 (outlet)	Primary Chamber Ash (1) Settling Chamber Ash (1)	Wire Insulation Feed (2) Transformer Feed (2)	None	Yes (3)	No
07/WFB-A	Yes (1)	Yes (1)	Yes	All Species No SO_2 (inlet)	Bottom Ash (1) Baghouse Dust (1)	Wood Fuel (2)	None	Yes (3)	No
08/BLB-C	Yes (1)	Yes (1)	Yes	All Species (outlet)	ESP Catch (1)	Strong Black Liquor (2) Fuel Oil (2)	Yes (1)	Yes (3)	Yes
09/CRF-A	Yes (1)	Yes (1)	Yes	All Species No SO_2, NO_x (outlet)	Reactivated Carbon (1) Baghouse Dust (1)	Spent Carbon Feed (2)	Yes (1)	No	No
10/MET-A	No	Yes (1)	Yes	All Species (outlet)	Baghouse Dust (1)	Coke (2) Plastic Bearing Feed Materials (2)	Yes (1)	Yes (3)	No
11/DBR-A	Yes (1)	Yes (1)	Yes	All Species (outlet)	Furnace Inlet Ash (1) Furnace Outlet Ash (1)	Drum Residues (2) Drum Coatings (2)	Yes (1)	Yes (3)	No

(Continued)

TABLE 5-1. (Continued)

Site	MM5 Dioxin/Furan Sampling[a] Inlet	MM5 Dioxin/Furan Sampling[a] Outlet	HCL Sampling	Continuous Emissions Monitoring	Ash Samples	Feed Samples	Ambient Air	Soils	Auxiliary Process Sampling
12/SSI-C	Yes (1)	Yes (1)	No	All Species (inlet)	Bottom Ash (1) Scrubber Blowdown: Solids (1), filtrate (1)	Feed Sludge (2)	Yes (2)	Yes (3)	No
13/WS-A	No	Yes (1)	No	All Species No SO_2, NO_x (outlet)	Bottom Ash (1) Stack Wipe (2)	Pine (2) Oak (2)	None	No	No

Inlet = Sampling performed on the inlet flue gas stream entering the air pollution control device.
Outlet = Sampling performed on the outlet flue gas stream leaving the air pollution control device.

[a] Numbers shown in parenthesis indicate dioxin/furan analytical priorities which are defined as follows:
  Priority 1 - Samples analyzed by Troika for dioxin/furan content.
  Priority 2 - Samples that will potentially be analyzed by Troika for dioxin/furan content, pending evaluation at the Priority 1 sample analysis.
  Priority 3 - Samples that will potentially be analyzed by Troika for dioxin/furan content, pending evaluation of the Priority 1 and 2 sample analyses.

[b] Continuous Emissions Monitoring refers to the monitoring of O_2, CO, CO_2, SO_2, NO_x and THC (Total Hydrocarbons). Concentrations of all six species have been monitored for each site, except where noted.

[c] Feed samples were analyzed for dioxin/furan precursor content and total chloride content, and are being held for Priority 2 dioxin/furan analysis.

because of the low CDD/CDF concentration measured in the stack samples. Three valid test runs were performed at each site except wire reclamation incinerator site WRI-A. At site WRI-A, three valid test runs were performed for each of two feed materials, which made a total of six valid test runs. Process operating conditions during the valid test runs at all sites were representative of normal operations; no major process upsets occurred during testing. The various sample types taken at each facility are discussed below.

5.1.1 CDD/CDF Emissions Sampling

Sampling for CDD/CDF emissions was the primary focus of the testing effort. The CDD/CDF sampling generally followed the Modified Method 5 (MM5) protocol now being adopted by the American Society of Mechanical Engineers (ASME) for measuring emissions of chlorinated organic compounds from municipal waste combustors. This stack sampling method is currently undergoing validation testing. Preliminary results indicate that recovery efficiencies from the sampling method may be low and variable, with possibly less than half of the CDD's and CDF's in the stack emissions being collected by the MM5 method. Additional validation testing is currently underway. Minor modifications were made to the protocol for the purposes of the Tier 4 program. The method used did not allow determination of particulate loading as a conventional MM5 protocol would. These modifications are discussed in the Tier 4 Quality Assurance Project Plan.[A]

MM5 samples were taken downstream of the emission control device (i.e., at the control device outlet location) at each test site to measure controlled emissions of CDD's and CDF's. At least 240 minutes of on-line MM5 sampling were performed at the control device outlet location of each test site. Where applicable and feasible, MM5 samples were also taken upstream of the control device (i.e., at the control device inlet location) to develop information on uncontrolled CDD/CDF emissions and CDD/CDF removal efficiencies of the various control devices. As shown in Table 5-1, inlet MM5 samples were taken at eight

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[A] National Dioxin Study--Tier 4 Combustion Sources. Quality Assurance Project Plan. EPA-450/4-84-014e.

of the thirteen Tier 4 test sites. Inlet MM5 sampling was performed at these sites during the same time period as the outlet MM5 sampling. Inlet MM5 samples were not taken at Sites ISW-A, SSI-B, WRI-A, MET-A, and WS-A. There was no control device at Site WS-A. Sampling ports were not available and/or not readily accessible at the control device inlet locations of the remaining sites.

5.1.2 HCl Sampling

Sampling for chloride emissions was performed using the HCl train at all test sites except for the three sewage sludge incinerator sites (Sites SSI-A SSI-B, and SSI-C) and the woodstove site (Site WS-A). The HCl train is similar to the EPA Method 5 train except that the water in the impingers is replaced with a sodium hydroxide or potassium hydroxide solution. The intent of the HCl sampling was to provide an indicator of the amount of chlorine-containing species present in the combustion gases. In each case, HCl sampling was performed at the control device outlet location.

As mentioned above, HCl sampling was not performed at sewage sludge incinerator sites SSI-A, SSI-B, and SSI-C. It was expected that only small quantities of HCl would pass through the water scrubbers controlling emissions from these incinerators. For this reason, HCl sampling was thought not to be cost-effective at these sites. HCl sampling was also not performed at woodstove Site WS-A.

5.1.3 Continuous Monitoring of Combustion Gases

Continuous monitoring of as many as six species (O_2, CO, CO_2, total hydrocarbons (THC), NO_x and SO_2) was performed to document the stability of combustion conditions at each test site. The monitoring was performed as close as possible to the combustion device outlet location (i.e., control device inlet) so that the potential for air in-leakage would be minimized. At several test sites, either SO_2 or SO_2 and NO_x monitoring was omitted. In these cases, it was felt that continuous monitoring of SO_2 and/or NO_x concentrations would not provide significant additional information on the stability of combustion conditions, relative to that provided by the O_2, CO, CO_2 and THC monitoring.

5.1.4 In-Plant Ambient Air Sampling

In-plant ambient air sampling was performed near the combustion air inlet at seven test sites where CDD/CDF or CDD/CDF precursors were potentially present either in the pre-combustion air or in a dilution air stream that was ultimately combined with the combustion device exhaust gas prior to atmospheric discharge. These samples were not intended to represent downwind ambient air samples from the source. The ambient air samples were taken using a sample train containing XAD-2 resin. Four of the ambient air samples were analyzed for CDD/CDF content (Sites MET-A, CRF-A, SSI-C and DBR-A). The remainder were not analyzed due to insufficient laboratory support.

5.1.5 Feed Sampling

Feed samples were taken at each test site, typically on an hourly basis. A composite of the hourly samples was prepared and split into three parts: one part was analyzed for CDD/CDF precursors including chlorophenols, chlorinated biphenyls, chlorobenzenes, and total halogenated organics; one part was analyzed for total chloride; and one part was retained for potential CDD/CDF analysis. Due to time and budget constraints, none of the feed samples have been analyzed for CDD's and CDF's.

5.1.6 Ash Samples

Bottom ash and/or fly ash samples were obtained at eleven of the test sites. These samples were submitted for CDD/CDF analysis. The purpose of the ash sampling effort was to determine whether the presence or absence of CDD/CDF in ash samples can be used as an indicator of the presence or absence of CDD/CDF in flue gas emissions. Electrostatic precipitator (ESP) catch samples for black liquor boiler Sites BLB-A and BLB-B were not obtained because a wet bottom ESP was used at Site BLB-A and at Site BLB-B the ESP catch is recycled directly into the black liquor circuit, and access points were not available for sampling. These were the only test sites for which ash samples were not obtained.

5.1.7 Soil Samples

Soil samples were taken at all Tier 4 test sites except Site CRF-A and Site WS-A. The soil samples were originally taken under the Tier 4 program, but most of them (10 out of 11) were transferred to Tier 7 for analysis. The Site MET-A sample was the only soil sample analyzed by Tier 4 for CDD/CDF content.

5.1.8 Auxiliary Process Samples

Auxiliary process samples were taken at the three black liquor boiler test sites (Sites BLB-A, BLB-B, and BLB-C). These samples, which consisted of various black liquor circuit intermediates, were analyzed for total chloride content. The reason for analyzing these samples was to determine the major input sources of chlorine to the black liquor circuit.

5.2 CDD/CDF EMISSIONS DATA

This section summarizes the CDD/CDF emissions data developed in the Tier 4 test program. Data are presented for the outlet flue gas streams emitted to the atmosphere for each site, and for flue gas streams upstream of a control device for sites where these data were obtained. Controlled and uncontrolled emission concentrations, mass emission rates, and scaled mass emission rates (i.e., emission factors) are presented for 2378-TCDD, total PCDD, and total PCDF. The concentration, emission rate, and scaled mass emission rate data are contained in Sections 5.2.1, 5.2.2, and 5.2.3, respectively. Contributions of the various homologues to the total PCDD and total PCDF emissions are discussed in Section 6.3 of Chapter 6. Homologue-specific emissions data for the various test sites are contained in Appendix A.

5.2.1 Flue Gas Concentration Data

In this section, average CDD/CDF emission concentration data are presented for each Tier 4 test site. Flue gas concentrations are adjusted to a reference oxygen level (3% O_2) to eliminate the effect of excess air dilution when comparing emissions from different test sites. Controlled emission concentrations are presented in Section 5.2.1.1, and uncontrolled emission concentrations are presented in Section 5.2.1.2. Quality assurance/quality control results for these data are discussed in Chapter 7.

5.2.1.1 Outlet Flue Gas Emission Concentrations. Table 5-2 lists the average outlet 2378-TCDD, total PCDD, total PCDF mass emission concentrations, and 2378-TCDD equivalent emission rates for each Tier 4 test site. Estimations of 2378-TCDD equivalents were derived using "2378-TCDD toxic equivalency factors (TEFs)" to compare the relative potency of one mixture of

TABLE 5-2. AVERAGE PCDD/PCDF OUTLET EMISSION CONCENTRATIONS FROM THE TIER 4 TEST SITES
(SITES RANKED BY TOTAL PCDD CONCENTRATION)

Total PCDD Outlet Concentration Rank	Test Site	Source Type/Control Device Type	Average Outlet PCDD/PCDF Emission Concentrations (ng/dscm @ 3% O_2) 2378-TCDD	Total PCDD	Total PCDF	2378-TCDD Equivalent Emission Rate (g/yr)[b]
1	MET-A	Secondary Copper Cupola Furnace/AB, BH	232	11,900	60,700	829[c]
2	WRI-A	Wire Reclamation Incinerator/AB (wire and transformer feed)	0.1	705	866	0.012
3	ISW-A	Industrial Solid Waste Incinerator/AB	4.5	625	2,390	0.74
4	WFB-A	Salt-Laden Wood Fired Boiler/BH	0.3	195	83.2	0.559
5	WRI-A	Wire Reclamation Incinerator/AB (wire only feed)	0.1	173	305	0.012
6	SSI-C	Sewage Sludge Incinerator/SCR	0.1	52.7	446	2.23
7	SSI-A	Sewage Sludge Incinerator/SCR	0.05	19.6	43.5	0.016
8	DBR-A	Drum and Barrel Incinerator/AB	0.05	5.0	27.0	0.009
9	CRF-A	Carbon Regeneration Furnace/AB,SD,BH	ND (0.2)	3.7	3.3	0.023
10	BLB-C	Black Liquor Boiler/ESP	ND (0.01)	2.9	2.1	0.253
11	SSI-B	Sewage Sludge Incinerator/SCR	ND (0.1)	1.6	27.6	0.044
12	BLB-B	Black Liquor Boiler/ESP	ND (0.03)	1.2	0.7	0.030
13	BLB-A	Black Liquor Boiler/ESP	ND (0.04)	0.8	0.6	0.027
14	WS-A	Woodstove/Uncontrolled	NR	NR	NR	--

[a] Analytical data for Sites MET-A and WRI-A did not satisfy the Tier 4 QA/QC criteria for all test runs. Values shown in this table correspond to average for all test runs. Values for individual runs are contained in Appendix A.

[b] 8160 operating hours per year.

[c] Based on 2378-TCDD concentration of 170 ng/dscm @ 3% O_2

ND = not detected (average detection limit in parenthesis)
NR = No valid analytical data were reported
AB = afterburner

BH = baghouse
SCR = scrubber
SD = spray dryer
ESP = electrostatic precipitator

CDD's and CDF's with a different mixture of CDD's and CDF's. The use of TEF's permits an estimation of the carcinogenicity of the mixture of CDD and CDF compounds relative to the known carcinogenicity of 2378-TCDD. The TEF's used in this analysis are presented in Table 5-3. The test sites are ranked in the table by average outlet total PCDD concentration. Data are available for all sites except Site WS-A (woodstove). Surrogate recovery data for Site WS-A were below acceptable limits developed in the Tier 4 analytical quality assurance document, and therefore data for this site were not reported by Troika. Two sets of data are shown for Site WRI-A, one for conditions of wire and transformer feed and one for conditions of wire-only feed.

Table 5-2 shows that PCDD's and PCDF's were detected in the outlet emissions from all test sites for which data were available. Average total PCDD outlet emission concentrations varied over four orders of magnitude, ranging from 0.8 ng/dscm @ 3% O_2 for Site BLB-A to 11,900 ng/dscm @ 3% O_2 for Site MET-A. The average total PCDD outlet emission concentration from secondary copper cupola furnace MET-A was more than a full order of magnitude higher than that of the next highest test site, wire reclamation incinerator WRI-A with wire and transformer feed. In general, run-to-run variations for each test site were less than the site-to-site variations shown in Table 5-2.

The 2378-TCDD isomer was detected in the outlet emissions from 7 of the 12 sites for which data were available. Detectable emission concentrations of 2378-TCDD ranged from 0.05 ng/dscm @ 3% O_2 for Site DBR-A to 232 ng/dscm @ 3% O_2 for Site MET-A. Detection limits at sites for which 2378-TCDD were not detected ranged from 0.01 ng/dscm @ 3% O_2 for Site BLB-C to 0.2 ng/dscm @ 3% O_2 for Site CRF-A. In general, the contribution of the 2378-TCDD isomer to the total PCDD outlet emissions was small but was found to be highly variable between test sites. The 2378-TCDD isomer ranged from 0.06 percent (Site WRI-A, wire-only feed) to 1.9 percent (Site MET-A) of the total PCDD outlet concentration at those sites for which 2378-TCDD was detected.

Outlet total PCDF emissions were typically of the same order of magnitude as total PCDD outlet emissions, although in most cases the total PCDF concentrations exceeded the total PCDD concentrations. Average total PCDF outlet emission concentrations varied over more than four orders of magnitude

TABLE 5-3. TOXIC EQUIVALENCY FACTORS USED IN ESTIMATING 2378-TCDD EQUIVALENTS[a]

Compound(s)	Toxic Equivalency Factor
2378-TCDD	1.0
Other TCDDs*	0.01
Penta-CDDs	0.5
Hexa-CDDs	0.04
Hepta-CDDs	0.001
Octa-CDDs	0.000
2378-TCDF	0.1
Other TCDFs*	0.001
Penta-CDFs	0.1
Hexa-CDFs	0.01
Hepta-CDFs	0.001
Octa-CDFs	0.000

*In situations where 2378-TCDD or TCDF were not chemically analyzed in the sample, total TCDDs and TCDFs will have a relative potency factor of 1.0 and 0.1, respectively.

[a] Reference: U.S. Environmental Protection Agency. Interim Procedures for Estimating Risks Associated with Exposures to Mixtures of Chlorinated-Dibenzodioxins and -Dibenzofurans (CDD and CDF). The Risk Assessment Forum, Washington, D.C. EPA 625/3-87-012.

from 60,700 ng/dscm @ 3% O_2 for Site MET-A to 0.6 ng/dscm @ 3% O_2 for Site BLB-A.

5.2.1.2 Control Device Inlet Flue Gas Concentrations. Table 5-4 shows the average control device inlet 2378-TCDD, total PCDD, and total PCDF flue gas concentrations for the eight Tier 4 test sites for which sampling was performed at the air pollution control device inlet location. Total PCDD and total PCDF data were reported by Troika for each of these sites except Site SSI-A. Surrogate recovery efficiencies for the scrubber inlet samples at Site SSI-A were below acceptable limits developed in the Tier 4 analytical quality assurance document, and therefore inlet flue gas PCDD/PCDF data were not reported by Troika for this site. Speciation for the 2378-TCDD isomer was performed by Troika for inlet samples from only four of the test sites due to time and budget constraints. However, the Troika analyst indicated that the 2378-TCDD isomer was less than 25 percent of the measured total TCDD values.

As shown in Table 5-4, PCDD's and PCDF's were detected in the control device inlet flue gas from all of the seven test sites for which data were available. Inlet total PCDD flue gas concentrations from these sites ranged from 1.8 ng/dscm @ 3% O_2 for Site BLB-A to 687 ng/dscm @ 3% O_2 for Site DBR-A. In most cases, the inlet total PCDD concentrations shown in Table 5-4 exceed the outlet total PCDD concentrations shown in Table 5-2, reflecting the removal efficiencies of the various emission control devices. However, Site WFB-A is a case in which the measured outlet total PCDD concentrations were actually greater than the inlet total PCDD concentrations. These results will be further addressed in Section 6.0.

The 2378-TCDD isomer was detected in the control device inlet flue gas from two of the four sites for which data were available. The average inlet 2378-TCDD flue gas concentrations for Sites DBR-A and CRF-A were 16.3 ng/dscm @ 3% O_2 and 0.09 ng/dscm @ 3% O_2, respectively. 2378-TCDD was not detected in the control device inlet flue gas from Sites BLB-A and BLB-B. The contribution of 2378-TCDD to total PCDD was nearly 3 percent for the control device inlet flue gas from Site DBR-A, which was the highest 2378-TCDD/total PCDD ratio measured in the Tier 4 study.

TABLE 5-4. AVERAGE CONTROL DEVICE INLET PCDD/PCDF EMISSION CONCENTRATIONS FROM THE TIER 4 TEST SITES (SITES RANKED BY OUTLET TOTAL PCDD CONCENTRATION)

Inlet Total PCDD Concentration Rank	Test Site	Source Type/Control Device Type	Average Inlet PCDD/PCDF Concentrations (ng/dscm @ 3% O_2)		
			2378-TCDD	Total PCDD	Total PCDF
1	MET-A	Secondary Copper Cupola Furnace/AB, BH	NS	NS	NS
2	WRI-A	Wire Reclamation Incinerator/AB (wire and transformer feed)	NS	NS	NS
3	ISW-A	Industrial Solid Waste Incinerator/AB	NS	NS	NS
4	WFB-A	Salt-Laden Wood Fired Boiler/BH	0.9	102	156
5	WRI-A	Wire Reclamation Incinerator/AB (wire-only feed)	NS	NS	NS
6	SSI-C	Sewage Sludge Incinerator/SCR	NR	114	507
7	SSI-A	Sewage Sludge Incinerator/SCR	NR	NR	NR
8	DBR-A	Drum and Barrel Incinerator/AB	16.4	687	2,170
9	CRF-A	Carbon Regeneration Furnace/AB,SD,BH	0.09	28.8	70.1
10	BLB-C	Black Liquor Boiler/ESP	NR	9.0	15.1
11	SSI-B	Sewage Sludge Incinerator/SCR	NS	NS	NS
12	BLB-B	Black Liquor Boiler/ESP	ND (0.05)	17.1	1.1
13	BLB-A	Black Liquor Boiler/ESP	ND (0.04)	1.8	1.5
14	WS-A	Woodstove/Uncontrolled	NR	NR	NR

ND = not detected (average detection limits in parenthesis)
NR = no valid analytical data were reported
AB = afterburner
NS = not sampled

BH = baghouse
SCR = scrubber
SD = spray dryer
ESP = electrostatic precipitator

Control device inlet total PCDF concentrations were typically of the same order of magnitude as the inlet total PCDD concentration, although in most cases the total PCDF concentration exceeded the total PCDD concentration. Black liquor boiler Site BLB-B was the only notable exception to this trend. The average control device inlet total PCDF flue gas concentrations for the seven sites for which data were available ranged from 1.1 ng/dscm @ 3% O_2 for Site BLB-B to 2,170 ng/dscm @ 3% O_2 for Site DBR-A.

5.2.2 Mass Emission Rate Data

In this section, average CDD/CDF emission rate data are presented for each Tier 4 test site. Discussion of the data is limited to the magnitude of mass emission rates. Relationships between 2378-TCDD, total PCDD, and total PCDF mass emission rates for individual test sites are identical to those noted in Section 5.2.1 since the mass emission rate of each species is merely a multiple of the mass emission concentration.

5.2.2.1 Outlet PCDD/PCDF Emission Rates. Table 5-5 shows the average outlet 2378-TCDD, total PCDD, and total PCDF mass emission rates for each Tier 4 test site. The test sites are ranked in the table by average outlet total PCDD mass emission rates. This ranking differs from that in Tables 5-2 and 5-4 because of the difference in flue gas flow rates between test sites.

The mean outlet total PCDD mass emission rates range from a high of 283,000 ug/hr for Site MET-A to a low of 12 ug/hr for Site SSI-A. This represents a between-site variation of more than four orders of magnitude. 2378-TCDD mass emission rates range from a high of 5,360 ug/hr for Site MET-A to a low of 0.1 ug/hr for Sites WRI-A and SSI-A. Detection limits for the 2378-TCDD mass emission rates for the 5 sites for which 2378-TCDD was not detected ranged from 1 ug/hr for Site SSI-B to 5 ug/hr for Site BLB-B. Total PCDF outlet mass emission rates ranged from 1,420,000 ug/hr for Site MET-A to 29 ug/hr for Site CRF-A, or five orders of magnitude.

5.2.2.2 Control Device Inlet PCDD/PCDF Mass Flow Rates. Table 5-6 shows the average control device inlet 2378-TCDD, total PCDD, and total PCDF mass flow rates for the eight Tier 4 test sites for which sampling was performed at the air pollution control device inlet location. As discussed in Section 5.2.1.2, total PCDD and total PCDF analytical data were reported by Troika for

TABLE 5-5. AVERAGE OUTLET PCDD/PCDF MASS EMISSION RATES FOR THE TIER 4 TEST SITES
(SITES RANKED BY TOTAL PCDD MASS EMISSION RATES)

Outlet Total PCDD Mass Emission Rate Rank	Test Site	Source Type/Control Device Type	Average Mass Emission Rates (ug/hr) 2378-TCDD	Total PCDD	Total PCDF
1	MET-A	Secondary Copper Cupola Furnace/AB, BH	5,360	283,000	1,420,000
2	WFB-A	Salt-Laden Wood Fired Boiler/BH	5.8	4,190	1,800
3	ISW-A	Industrial Solid Waste Incinerator/AB	13.5	1,810	6,780
4	SSI-C	Sewage Sludge Incinerator/SCR	2.1	780	6,570
5	BLB-C	Black Liquor Boiler/ESP	ND (1.6)	667	330
6	WRI-A	Wire Reclamation Incinerator/AB (wire and transformer feed)	0.1	522	626
7	BLB-B	Black Liquor Boiler/ESP	ND (5.1)	230	214
8	BLB-A	Black Liquor Boiler/ESP	ND (7.2)	149	114
9	WRI-A	Wire Reclamation Incinerator/AB (wire-only feed)	0.1	113	205
10	SSI-A	Sewage Sludge Incinerator/SCR	0.1	40.5	90.4
11	CRF-A	Carbon Regeneration Furnace/AB,SD,BH	ND (2.0)	31.6	28.9
12	DBR-A	Drum and Barrel Incinerator/AB	0.3	23.8	129
13	SSI-B	Sewage Sludge Incinerator/SCR	ND (1.0)	11.6	194
14	WS-A	Woodstove/Uncontrolled	NR	NR	NR

[a] Analytical data for Sites MET-A and WRI-A did not satisfy the Tier 4 QA/QC criteria for all test runs. Values shown correspond to averages for all test runs. Values for individual runs are contained in the corresponding site-specific test reports.

ND = not detected (average detection limit in parenthesis)
AB = afterburner
BH = baghouse
NR = no valid analytical data were reported

SCR = scrubber
SD = spray dryer
ESP = electrostatic precipitator

TABLE 5-6. AVERAGE CONTROL DEVICE INLET PCDD/PCDF MASS FLOW RATES FOR THE TIER 4 TEST SITES
(SITES RANKED BY OUTLET TOTAL PCDD MASS EMISSION RATES)

Outlet Total PCDD Mass Emission Rate Rank	Test Site	Source Type/Control Device Type	Average Inlet PCDD/PCDF Mass Flow Rates (ug/hr)		
			2378-TCDD	Total PCDD	Total PCDF
1	MET-A	Secondary Copper Cupola Furnace/AB, BH	NS	NS	NS
2	WFB-A	Salt-Laden Wood Fired Boiler/BH	24.0	2,640	4,380
3	ISW-A	Industrial Solid Waste Incinerator/AB	NS	NS	NS
4	SSI-C	Sewage Sludge Incinerator/SCR	NR	1,790	7,900
5	BLB-C	Black Liquor Boiler/ESP	NR	1,060	1,810
6	WRI-A	Wire Reclamation Incinerator/AB (wire and transformer feed)	NS	NS	NS
7	BLB-B	Black Liquor Boiler/ESP	ND (9.4)	3,380	383
8	BLB-A	Black Liquor Boiler/ESP	ND (8.0)	339	283
9	WRI-A	Wire Reclamation Incinerator/AB (wire-only feed)	NS	NS	NS
10	SSI-A	Sewage Sludge Incinerator/SCR	NR	NR	NR
11	CRF-A	Carbon Regeneration Furnace/AB,SD,BH	1.0	310	754
12	DBR-A	Drum and Barrel Incinerator/AB	24.2	1,050	3,110
13	SSI-B	Sewage Sludge Incinerator/SCR	NS	NS	NS
14	WS-A	Woodstove/Uncontrolled	NR	NR	NR

NR = no valid analytical data were reported
ND = not detected (average detection limit in parenthesis)
NS = not sampled
SD = spray dryer

AB = afterburner
BH = baghouse
SCR = scrubber
ESP = electrostatic precipitator

only seven of these sites because surrogate recovery efficiencies for Site SSI-A were below acceptable limits. Troika reported 2378-TCDD speciation for only four of these sites due to time and budget constraints.

The mean control device inlet total PCDD mass flow rates for the seven sites for which data are available range from 3,380 ug/hr for Site BLB-B to 310 ug/hr for Site CRF-A. The mean inlet 2378-TCDD mass flow rates for Sites CRF-A and DBR-A were 1 ug/hr and 24 ug/hr, while 2378-TCDD was not detected in the control device inlet flue gas from Sites BLB-A and BLB-B. The mean inlet total PCDF mass flow rates ranged from 283 ug/hr for Site BLB-A to 7,900 ug/hr for Site SSI-C.

5.2.3 Scaled Mass Emissions Data

Average outlet and inlet PCDD/PCDF scaled mass emissions (i.e., emissions per unit of feed) are presented in Tables 5-7 and 5-8 for each Tier 4 test site. The scaled mass emissions were calculated by dividing the PCDD/PCDF emission rates (ug/hr) by a representative mass feed rate to the combustion device (e.g., kg/hr dry solids for the black liquor boilers). Scaled mass emissions for various source types are not directly comparable because they are based on different feed materials.

Tables 5-7 and 5-8 give the feed rate basis for each test site along with the outlet and inlet scaled mass emissions for 2378-TCDD, total PCDD, and total PCDF. Homologue-specific scaled mass emissions are contained in the individual test report for each site. The test sites are grouped by source category in Tables 5-7 and 5-8.

5.3 CDD/CDF PRECURSOR DATA

This section summarizes the CDD/CDF precursor analyses performed on feed samples from the Tier 4 test sites. Homologue-specific precursor analyses were performed using gas chromatography and mass spectrometry (GC/MS). Specific precursors analyzed for using the GC/MS were chlorobenzenes, chlorinated biphenyls, and chlorophenols. Chapter 7 of this report includes a discussion of the difficulties encountered during the precursor analyses, along with a summary of the quality assurance/quality control results.

TABLE 5-7. AVERAGE OUTLET SCALED PCDD/PCDF MASS EMISSIONS FOR THE TIER 4 TEST SITES

Test Site	Basis of Feed Rate Scaling Factor[a]	Average Outlet Scaled Mass Emissions (ug/kg)		
		2378-TCDD	Total PCDD	Total PCDF
Sewage Sludge Incinerators				
SSI-A	Dry Sludge Feed Rate	2.2×10^{-4}	1.0×10^{-1}	2.3×10^{-1}
SSI-B	Dry Sludge Feed Rate	ND(3.4×10^{-4})	4.8×10^{-3}	8.3×10^{-2}
SSI-C	Dry Sludge Feed Rate	9.4×10^{-4}	3.6×10^{-1}	3.0×10^{0}
Black Liquor Boilers				
BLB-A	Dry Solids Feed Rate	ND(1.3×10^{-4})	2.8×10^{-3}	2.1×10^{-3}
BLB-B	Dry Solids Feed Rate	ND(8.9×10^{-5})	4.1×10^{-3}	2.4×10^{-3}
BLB-C	Dry Solids Feed Rate	ND(3.8×10^{-5})	1.6×10^{-2}	7.9×10^{-3}
Wood Combustion				
WFB-A	Wood Feed Rate (wet)	9.9×10^{-4}	7.1×10^{-1}	3.1×10^{-1}
WS-A	Wood Feed Rate (wet)	NR	NR	NR
ISW-A	Total Solids Feed Rate	1.3×10^{-2}	1.7×10^{0}	6.3×10^{0}
Metals Recovery				
MET-A	Copper-Bearing Feed Rate	1.3×10^{-1}	6.4×10^{0}	$3.3 \times 10^{+1}$
WRI-A (wire only)	Total Solids Feed Rate	2.8×10^{-4}	3.6×10^{-1}	6.3×10^{-1}
WRI-A (wire & transformers)	Total Solids Feed Rate	3.7×10^{-4}	1.4×10^{0}	1.8×10^{0}
Miscellaneous Sources				
DBR-A	Drum Feed Rate[b]	2.1×10^{-3}	2.0×10^{-1}	1.1×10^{0}
CRF-A	Spent Carbon Feed Rate	ND(2.1×10^{-3}	3.1×10^{-2}	2.7×10^{-2}

ND = not detected (average detection limit in parenthesis)

[a] All scaled mass emissions calculated using feed rates expressed in units of kg/hr of the specified feed material except for Site DBR-A, for which the feed rate was expressed in units of number of drums processed per hour.

[b] Scaled mass emissions for Site DBR-A are based on the number of drums processed per hour.

TABLE 5-8. AVERAGE CONTROL DEVICE INLET SCALED PCDD/PCDF MASS FLOW FOR THE TIER 4 TEST SITES

Test Site	Basis of Feed Rate Scaling Factor[a]	Average Scaled Inlet PCDD/PCDF Mass Flow (ug/kg)		
		2378-TCDD	Total PCDD	Total PCDF
Sewage Sludge Incinerators				
SSI-A	Dry Sludge Feed Rate	NR	NR	NR
SSI-B	Dry Sludge Feed Rate	NS	NS	NS
SSI-C	Dry Sludge Feed Rate	NR	8.2×10^{-1}	3.6×10^{0}
Black Liquor Boilers				
BLB-A	Dry Solids Feed Rate	ND(1.4×10^{-4})	6.3×10^{-3}	5.3×10^{-3}
BLB-B	Dry Solids Feed Rate	ND(1.7×10^{-4})	5.9×10^{-2}	3.7×10^{-3}
BLB-C	Dry Solids Feed Rate	NR	2.5×10^{-2}	4.1×10^{-2}
Wood Combustion				
WFB-A	Wood Feed Rate (wet)	4.1×10^{-3}	4.9×10^{-1}	7.5×10^{-1}
WS-A	Wood Feed Rate (wet)	NR	NR	NR
ISW-A	Total Solids Feed Rate	NS	NS	NS
Metals Recovery				
MET-A	Copper-Bearing Feed Rate	NS	NS	NS
WRI-A (wire only)	Total Solids Feed Rate	NS	NS	NS
WRI-A (wire & transformers)	Total Solids Feed Rate	NS	NS	NS
Miscellaneous Sources				
DBR-A	Drum Feed Rate[b]	2.1×10^{-1}	8.8×10^{0}	2.6×10^{1}
CRF-A	Spent Carbon Feed Rate	8.9×10^{-4}	3.0×10^{-1}	7.0×10^{-1}

[a] All emission factors calculated using feed rates expressed in units of kg/hr of the specified feed material except for Site DBR-A, for which the feed rate was expressed in units of number of drums processed per hour.

[b] Emission factors for Site DBR-A are based on the number of drums processed per hour.

NS = uncontrolled emissions not sampled; NR = analytical data not reported; NA = feed rate data not available

Total organic halogen (TOX) analyses were performed on selected samples using short column gas chromatography with a Hall detector. The TOX procedure is incapable of speciation and gives a positive response to any organic halide. The TOX procedure was applied primarily to sample media for which the GC/MS analysis was not completely successful. Samples analyzed using the TOX procedure included the cardboard/paper/wood samples and the wood/plastic parts samples from Site ISW-A, the electrical switching gear sample and circuit board samples from Site MET-A, the wire coating/wire insulation samples and transformer core samples from Site WRI-A, the drum coating samples from Site DBR-A, and the spent carbon samples from Site CRF-A. Additional TOX analyses were carried out on·at least one sample of each medium type. These additional TOX samples included fuel oil samples from Sites SSI-A, ISW-A, and BLB-B; a sewage sludge sample from Site SSI-C; a strong black liquor sample from Site BLB-B; and a wood sample from Site WFB-A.

Table 5-9 summarizes the GC/MS and TOX precursor results. The data show a wide range of precursor contents across the various source categories. Precursor data within source categories are generally consistent. The data for each source category are discussed below.

5.3.1 Sewage Sludge Incinerator Test Sites

Sewage sludge samples from the sewage sludge incinerator test sites SSI-A, SSI-B, and SSI-C were found to contain small quantities of chlorobenzenes. The total chlorobenzene content of individual sewage sludge samples ranged from less than the detectable level to about 40 ppb. Dichlorobenzene was the only chlorobenzene detected. Site SSI-B sludge samples appear to have contained more chlorobenzenes than Site SSI-A or SSI-C samples. Detectable quantities of chlorobenzenes were found in each of the three sludge samples analyzed from Site SSI-B, whereas chlorobenzenes were not detected in at least one sludge sample from each of Sites SSI-A and SSI-C. Chlorinated biphenyls and chlorophenols were not detected in the sludge samples from any of the three sewage sludge incinerator sites.

A sludge sample from Site SSI-C and a fuel oil sample from Site SSI-A were analyzed using the TOX procedure. These samples were found to contain less than the detectable level of total TOX which in this analysis was 10 ppm.

TABLE 5-9. DIOXIN/FURAN PRECURSOR DATA SUMMARY

		GC/MS Precursor Analysis			Hall Detector Analysis	Ion Chromatography Analysis
		Base/Neutrals Fraction		Acids Fraction		
Source Category/ Test Site	Sample Type	Chlorobenzene (ug/g)	Chlorinated Biphenyls (ug/g)	Chlorophenols (ug/g)	Total TOX (ug/g)	Total Cl (ug/g)
Sewage Sludge Incinerators						
SSI-A	Sludge Feed	ND - 0.01	ND	ND	NA	600
	Fuel Oil	NA	NA	NA	ND	35
SSI-B	Sludge Feed	0.01 - 0.04	ND	ND	NA	240
SSI-C	Sludge Feed	ND - 0.03	ND	ND	ND	300
Black Liquor Boilers						
BLB-A	Black Liquor	ND	ND	ND - 0.014	NA	900
BLB-B	Black Liquor	ND	ND	ND - Trace	ND	5,280
BLB-C	Black Liquor	ND	ND	ND - 0.01	NA	3,350
	Fuel Oil	NA	NA	NA	ND	170
Wood Combustion						
WFB-A	Wood Feed	ND	ND	ND	ND	1,880
WS-A	Oak	ND	ND	ND	NA	125
	Pine	ND	ND	ND	NA	49

(Continued)

TABLE 5-9. DIOXIN/FURAN PRECURSOR DATA SUMMARY (Continued)

		GC/MS Precursor Analysis			Hall Detector Analysis	Ion Chromatography Analysis
		Base/Neutrals Fraction		Acids Fraction		
Source Category/ Test Site	Sample Type	Chlorobenzene (ug/g)	Chlorinated Biphenyls (ug/g)	Chlorophenols (ug/g)	Total TOX (ug/g)	Total Cl (ug/g)
Wood Combustion (Continued)						
ISW-A	Cardboard, paper, and wood	ND	ND	0.04 - 0.11		9668
	Wood and plastic parts	ND	ND - 0.05	5.7 - 19.7	12.7[a]	NA
	Oil-based paint sludge	ND	ND	ND - 0.03	NA	NA
	Latex paint sludge	ND	ND - Trace	Trace - 0.03	NA	NA
	Fuel oil	ND	ND	ND	ND - 22.2	30
Metals Recovery						
MET-A	Metallurgical coke	ND	ND	ND	NA	NA
	Miscellaneous telephone parts and wire	ND	0.004	ND	NA	NA
	Circuit boards	ND	ND	ND	4,303[b]	NA
	Electrical switching gear	ND	0.26	ND		NA

(Continued)

TABLE 5-9. DIOXIN/FURAN PRECURSOR DATA SUMMARY (Continued)

Source Category/ Test Site	Sample Type	GC/MS Precursor Analysis: Base/Neutrals Fraction: Chlorobenzene (ug/g)	GC/MS Precursor Analysis: Base/Neutrals Fraction: Chlorinated Biphenyls (ug/g)	GC/MS Precursor Analysis: Acids Fraction: Chlorophenols (ug/g)	Hall Detector Analysis: Total TOX (ug/g)	Ion Chromatography Analysis: Total Cl (ug/g)
Metals Recovery (Continued)						
WRI-A	Wire coating and insulation	ND	ND	Trace	201	NA
	Transformer core parts (cardboard, wood, paper)	ND^c	ND^c	0.2	20.9 - 24.1	270
Miscellaneous Sources						
DBR-A	Drum residue (solvent)	ND - 68.6	ND	ND	802	4,700
	Drum coating	ND - 0.22	ND	ND	NA	50
CRF-A	Spent carbon	0.16 - 6.63	ND	ND	154	6,400

ND = not detected
NA = not analyzed

[a] TOX analysis was performed on a composite of the cardboard, paper, and wood samples and the wood and plastic parts samples.

[b] TOX analysis was performed on a composite of the circuit board samples and the electrical switching gear samples.

[c] The base/neutrals fraction of this sample could not be analyzed successfully by GC/MS. The sample was analyzed for Total Organic Halogen and a chromatographic profile was obtained by gas chromatography using electron capture detection.

5.3.2 Black Liquor Boiler Test Sites

Strong black liquor samples from test sites BLB-A, BLB-B, and BLB-C were found to contain small quantities of chlorophenols. Pentachlorophenol was the only chlorophenol homologue detected. The total chlorophenol content of individual black liquor samples ranged from less than the detectable level to about 14 ppb. Chlorophenols were not detected in at least one black liquor sample from each of the black liquor boiler test sites. Chlorobenzenes and chlorinated biphenyls were not detected in the strong black liquor samples from any of the sites.

A black liquor sample and a fuel oil sample from site BLB-B were analyzed using the TOX procedure. These samples were found to contain less than the detectable level of total TOX (i.e., <10 ppm).

5.3.3 Wood Combustion Test Sites

Wood samples from wood-fired boiler WFB-A and woodstove WS-A were found to contain less than detectable quantities of all precursors analyzed for (i.e., chlorobenzenes, chlorinated biphenyls, and chlorophenols). A wood sample from Site WFB-A analyzed using the TOX procedure was found to contain less than 10 ppm of total TOX (i.e., <10 ppm).

Feed materials from industrial solid waste incinerator site ISW-A, which is included in the wood combustion category, were found to contain small quantities of chlorinated biphenyls and small to large quantities of chlorophenols. Chlorobenzenes were not detected in any of the feed materials from this site. Chlorinated biphenyls were detected in the wood/plastic parts samples and in the latex paint sludge samples. The total chlorinated biphenyl content of individual samples of these materials ranged from non-detectable to 50 ppb. Chlorophenols were the most prevalent precursor species present in the feed materials from site ISW-A. Small quantities of chlorophenols (ranging from non-detectable to about 100 ppb) were found in the cardboard/paper/wood samples, the oil-based paint sludge samples, and the latex paint sludge samples. Large quantities of tetra- and pentachlorophenols were found in the wood/plastic parts samples. The total chlorophenol content of individual wood/plastic parts samples ranged from 5,700 to 19,700 ppb.

A composite of the cardboard/paper/wood samples and wood/plastic parts samples from Site ISW-A was analyzed using the TOX procedure. The composite sample was found to contain about 13 ppm total TOX. The fuel oil samples from each test run at site ISW-A were also analyzed using the TOX procedure. One of the samples (Run 02) was found to contain about 24 ppm total TOX, while the other two samples contained less than detectable levels of total TOX. The detection limit for the TOX analysis was 10 ppm.

5.3.4 Metals Recovery Test Sites

Samples of the plastic-bearing feed materials from Site MET-A were found to contain small quantities of chlorinated biphenyls. The total chlorinated biphenyl content of individual samples ranged from less than the detectable level for the metallurgical coke and circuit board samples to 260 ppb for the electrical switching gear samples. Chlorobenzenes and chlorophenols were not detected in any of the samples from Site MET-A.

A composite of the circuit board sample and the electrical switching gear samples from Site MET-A was analyzed using the TOX procedure. The circuit board/electrical switching gear composite sample was found to contain approximately 4,300 ppm total TOX, which was the highest TOX content of any sample analyzed in the Tier 4 program. Thus, although the specific precursors analyzed for (i.e., chlorobenzenes, chlorinated biphenyls, and chlorophenols) were found in only small quantities, there were significant quantities of halogenated species present in the feed material from site MET-A. This suggests that either 1) the specific precursors analyzed for were present in the samples but were not easily detected using the GC/MS procedure due to the complexity of the sample matrix, or 2) significant quantities of halogenated species other than the specific precursors analyzed for were present in the samples. One potential source of these "other" halogenated species is polyvinyl chloride.

Feed materials from wire reclamation incinerator WRI-A included wire coating/insulation and transformer core parts (cardboard, paper, and wood components of the transformer cores). Small quantities of chlorophenols (i.e., less than 200 ppb) were found in both materials. Chlorobenzenes and chlorinated biphenyls were not detected in the wire samples, but these species could not be successfully analyzed for in the transformer samples using the GC/MS procedure due to the complexity of the sample matrix. Based on conversations with plant personnel at Site WRI-A, it is believed that chlorinated biphenyls were present in the transformer samples, but the amount is unknown.

The total TOX contents of the wire and transformer samples from Site WRI-A were approximately 200 ppm and 20 ppm, respectively. Again, this suggests that either 1) the specific precursors analyzed for were present in the samples but were not easily detected using the GC/MS procedure due to the complexity of the sample matrix, or 2) significant quantities of halogenated species other than the specific precursors analyzed for were present in the samples. One potential source of these "other" halogenated species is polyvinyl chloride.

5.3.5 Other Test Sites

Combustible materials in the feed to drum and barrel reclamation incinerator DBR-A included solvent residue contained in the drums and the coating on the surface of the drums. Chlorobenzenes were detected in both materials, but chlorinated biphenyls and chlorophenols were not detected in either material. The total chlorobenzene content of solvent residue samples from individual test runs ranged from below the detectable level (Run 03) to nearly 70,000 ppb (Run 01). This reflects the random nature of drum types processed in the unit. Trichlorobenzenes were the predominant species found in the solvent residue samples, with small quantities of dichlorobenzenes also detected.

The total chlorobenzene content of the drum coating was approximately 220 ppb, with trichlorobenzenes being the only species detected.

A solvent residue sample from Site DBR-A analyzed using the TOX procedure was found to contain about 800 ppm total TOX, which was the second highest total TOX content found in the Tier 4 program.

Spent carbon samples from carbon regeneration furnace CRF-A were found to contain variable quantities of chlorobenzenes, but chlorinated biphenyls and chlorophenols were not detected. The total chlorobenzene content of individual spent carbon samples ranged from 160 ppb (Run 02) to 6,630 ppb

(Run 03). Trichlorobenzenes were the predominant species present, with small quantities of di- and tetra-chlorobenzenes also detected. A spent carbon sample analyzed using the TOX procedure was found to contain about 150 ppm total TOX.

5.4 HCl SAMPLING DATA

This section summarizes the chloride emissions data developed using the HCl train. The data are reported as "front-half", "back half", and "train total" chloride emissions. The front-half emissions represent chlorides captured in the probe rinse/filter fraction of the HCl train, which may include metal chlorides contained in the particulate matter (e.g., NaCl) and the back-half emissions include chlorides captured in the impingers, which would include HCl plus any metal chlorides that pass through the sample train filter. The train-total emissions represent the sum of the front-half and back-half emissions.

The data in Table 5-10 show a wide range of chloride emissions for the various test sites. The mean train-total chloride concentrations range from a high of nearly 10,800 mg/dscm @ 3% O_2 for industrial solid waste incinerator ISW-A to a low of less than 5 mg/dscm @ 3% O_2 for carbon regeneration furnace CRF-A and black liquor boiler BLB-B. Other sites with relatively high chloride emissions included wire reclamation incinerator WRI-A, which had chloride emissions of approximately 1,000 mg/dscm @ 3% O_2. Chloride emissions from the black liquor boiler source category showed considerable variation between test sites. Total chloride emissions from Site BLB-B were 2.9 mg/dscm @ 3% O_2, considerably lower than those from sites BLB-A and BLB-C, which were 112 and 185 mg/dscm @ 3% O_2, respectively. Site BLB-B is a direct contact black liquor boiler, while Sites BLB-A and BLB-C are low-odor black liquor boilers. The direct flue gas/weak liquor contact at Site BLB-B apparently acted as a scrubber in removing chloride species from the flue gas.

The distribution of total chloride emissions between the front-half and back-half of the sample train varied between test sites. The total chloride was predominantly distributed in the back-half of the sample train for Sites BLB-A, BLB-C, ISW-A, and DBR-A. Greater than 90 percent of the total

TABLE 5-10. HCl TRAIN EMISSIONS DATA SUMMARY

Source Category/ Test Site	Mean Chloride Concentration (mg/dscm @ 3% O_2)		
	Front-Half	Back-Half	Total
Sewage Sludge Incinerators			
SSI-A	NS	NS	NS
SSI-B	NS	NS	NS
SSI-C	NS	NS	NS
Black Liquor Boilers			
BLB-A	1.5	110	112
BLB-B	2.2	0.7	2.9
BLB-C[a]	12.5	173	185
Wood Combustion			
WFB-A	39.5	155	195
WS-A	NS	NS	NS
ISW-A	168	10,600	10,800
Metals Recovery			
MET-A	33.6	26.1	59.7
WRI-A (wire only)	438	385	820
WRI-A (wire and transformers)	249	1,050	1,300
Miscellaneous Sources			
DBR-A	0.39	92.7	93
CRF-A	1.7	1.7	3.4

[a] Mean values shown for Site BLB-C include data for Runs 01 and 02 only.
NS = not sampled

chlorides was found in the back-half of the sample train for these sites. This indicates the potential for a high proportion of HCl emissions. The total chloride was more evenly distributed between the front- and back-halves of the sample trains for Sites BLB-B, WFB-A, MET-A, WRI-A, and CRF-A. For these test sites a significant portion of the total chloride emissions may have been associated with less reactive metal chloride species, rather than the more reactive HCl.

5.5 CONTINUOUS EMISSIONS MONITORING DATA

This section summarizes the continuous monitoring data obtained for O_2, CO, THC, SO_2, NO_x, and CO_2. The data are summarized by giving the mean and standard deviation of the individual 5-minute concentration values obtained during the test runs. The mean concentrations and standard deviations of the six species monitored for at the various test sites are shown in Table 5-11. Graphic displays and tabular summaries of the 5-minute values are contained in the site-specific test reports. Concentrations of CO, THC, SO_2, NO_x, and CO_2 have been corrected to a reference oxygen level (3% O_2) to eliminate the effect of excess air dilution when comparing data between various test sites.

Mean oxygen concentrations measured at the five test sites for which monitoring was performed at the control device inlet location ranged from 6.0% O_2 for Site BLB-A to 13.2% O_2 for Site SSI-C. The range for control device outlet locations was 5.7% O_2 for Site WRI-A (wire-only runs) to 20.2% O_2 for Site MET-A. Thus, there were significant variations in excess combustion air and/or flue gas dilution air between test sites. Normalization of the CO, THC, SO_2, and NO_x concentrations to 3% O_2 minimizes the effects of excess air dilution and allows for a fair comparison of data between test sites.

Mean CO concentrations varied over several orders of magnitude. Sites CRF-A, BLB-A, DBR-A, WFB-A, and ISW-A had the lowest mean CO concentrations, with mean values ranging from about 100 to 400 ppmv CO @ 3% O_2. Sites WS-A, MET-A, and BLB-B had the highest mean CO concentrations, with mean values exceeding 10,000 ppmv CO @ 3% O_2. Several of the test sites showed significant CO variations within test runs and/or between test runs.

TABLE 5-11. MEAN VALUES AND STANDARD DEVIATIONS OF THE CONTINUOUSLY MONITORED STACK GASES[a]

Test Site	Monitoring Location	O_2 % Vol	CO ppmv @3%O_2	THC ppmv @3%O_2	SO_2 ppmv @3%O_2	NO_x ppmv @3%O_2	CO_2 % Vol @3%O_2
Sewage Sludge Incinerators							
SSI-A	Scrubber Inlet	11.9 (1.7)	2,473 (860)	152.3 (100)	1,587 (560)	465.3 (210)	29.5 (8.9)
SSI-B	Scrubber Inlet	13.1 (0.5)	4,677 (750)	22.7 (9.2)	NS[b]	788.0 (65)	18.9 (2.8)
SSI-C	Scrubber Inlet	13.2 (1.1)	3,113 (723)	NS	504 (72.2)	419 (54.8)	13.1 (1.1)
Black Liquor Boilers							
BLB-A	ESP Inlet	6.0 (0.3)	136 (98)	3.5 (4.1)	94 (77)	83.2 (5.4)	15.6 (1.2)
BLB-B	ESP Inlet	12.2 (0.8)	10,900 (2,400)	57.7 (39)	830 (220)	42.6 (12)	17.4 (1.5)
BLB-C	ESP Outlet	12.2 (1.1)	862 (360)	23.0 (11)	80 (41)	40.9 (2.5)	17.0 (0.6)
Wood Combustion							
WFB-A	Baghouse Outlet	13.0 (0.9)	273 (120)	1.9 (1.9)	NS	0.3 (0.3)	17.9 (0.6)
WS-A	Woodstove Outlet	17.0 (0.4)	36,900 (6,000)	49,500 (7,700)	NS	NS	15.8 (1.7)
ISW-A	Incinerator Outlet	11.4 (1.5)	370 (140)	7.2 (2.4)	NS	128.3 (27)	15.9 (1.6)
Metals Recovery							
MET-A	Baghouse Outlet	20.2 (0.5)	30,800 (23,500)	371 (284)	7,290 (1,760)	940 (230)	43.8 (5.0)
WRI-A (wire only)	Afterburner Outlet	5.7 (2.9)	4,657 (3,800)	276.5 (260)	NS	89.2 (40)	12.9 (1.4)

(Continued)

TABLE 5-11. MEAN VALUES AND STANDARD DEVIATIONS OF THE CONTINUOUSLY MONITORED STACK GASES[a] (Continued)

Test Site	Monitoring Location	O_2 % Vol	CO ppmv @3%O_2	THC ppmv @3%O_2	SO_2 ppmv @3%O_2	NO_x ppmv @3%O_2	CO_2 % Vol @3%O_2
WRI-A (wire & transformers)	Afterburner Outlet	7.4 (2.7)	5,605 (3,500)	877.5 (1,100)	NS	126.1 (50)	14.1 (2.5)
Miscellaneous Sources							
DBR-A	Afterburner Outlet	13.5 (1.1)	234 (163)	5.6 (11.3)	18.9 (18.1)	132 (32.2)	11.8 (0.7)
CRF-A	Baghouse Outlet	13.9 (0.3)	89 (120)	3.0 (2.9)	NS	NS	13.2 (0.4)

[a] Mean value shown on top, with standard deviation shown below in parenthesis.

[b] NS = not sampled.

Mean THC emissions also showed significant variability between test sites. With the exception of Site WS-A, mean THC concentrations ranged from less than 10 ppmv @ 3% O_2 for Sites WFB-A, CRF-A, BLB-A, DBR-A, and ISW-A to greater than 100 ppmv @ 3% O_2 for Sites WRI-A, MET-A, SSI-A, and BLB-B. The THC concentration for Site WS-A (49,500 ppmv @ 3% O_2) was more than 50 times greater than that of the next highest site (WRI-A/wire and transformers, 880 ppmv @ 3% O_2). In general, flue gas concentrations of THC and CO tended to be positively correlated. Sites with low mean CO concentrations tended to have low mean THC concentrations, and sites with high mean CO concentrations tended to have high mean THC concentrations as would be expected from fundamental combustion theory.

Mean concentrations of SO_2 and NO_x also showed significant variations between test sites. The SO_2 concentrations ranged from about 20 ppmv @ 3% O_2 for Site DBR-A to 4,440 ppmv @ 3% O_2 for Site MET-A. The NO_x concentrations ranged from less than 1 ppmv @ 3% O_2 for Site WFB-A to about 800 ppmv @ 3% O_2 for Sites MET-A and SSI-B.

5.6 PROCESS DATA

This section summarizes the process data obtained at each test site. Combustion device operating data are presented in Section 5.6.1, and control device operating data are presented in Section 5.6.2.

5.6.1 Combustion Device Operating Data

Table 5-12 summarizes the combustion device operating data obtained at each test site. Key operating parameters included process rate data, feed characterization data, process temperature data, and excess combustion air data. These data are discussed in detail in the individual site-specific test reports.

5.6.2 Emissions Control Device Operating Data

Tables 5-13, 5-14, and 5-15 summarize the emissions control device operating data obtained at each test site. These data are discussed in detail in the individual site-specific test reports.

TABLE 5-12. MEAN COMBUSTION DEVICE OPERATING PARAMETERS DURING THE TEST RUNS

Source Category/ Test Site	Combustion Device Type	Process Feed Rate	Feed Characteristics	Auxiliary Fuel Firing Rate(s)	Process Temperatures		Oxygen (% O_2)[a]
					Maximum	Other	
Sewage Sludge Incinerators							
SSI-A	Multiple (6) Hearth Incinerator	398 kg/hr (dry solids) Continuous Feed	21.1 wt.% dry solids 69.0% volatile solids	0.05 cmh No.2 fuel oil; 71 cmh digester gas	781°C (middle hearth)	424°C (top hearth)	11.9 (furnace outlet)
SSI-B	Multiple (9) Hearth Incinerator (1983)	2,600 kg/hr (dry solids) Continuous Feed	36.2 wt.% dry solids 74.7% volatile solids	None	869°C (middle hearth)	622°C (top hearth)	13.1 (furnace outlet)
SSI-C	Multiple Hearth Incinerator (12 hearths, 1974)	2,600 kg/hr (dry solids) Continuous Feed	20.3 wt.% dry solids 55.1 wt.% volatiles, (dry basis)	None	741°C (middle hearth)	444°C (top hearth)	13.2 (furnace outlet)
Black Liquor Boilers							
BLB-A	900 TPD B&W Low Odor Recovery Boiler (1983)	53,900 kg/hr (dry solids) Continuous Feed	65.0 wt.% solids	None	NA	--	3.6[a] (economizer)
BLB-B	800 TPD CE Direct Contact Recovery Boiler (193)	56,800 kg/hr (dry solids) Continuous Feed	70.3 wt.% solids	None	NA	--	2.3[a] (economizer)
BLB-C	850 TPD CE Low Odor Recovery Boiler (1973)	43,000 kg/hr (dry solids) Continuous Feed	63.1 wt.% solids	0.4 cmh Bunker C oil (Run 03 only)	NA	--	2.7[a] (boiler outlet)
Wood Combustion							
WFB-A	100,000 lb/hr steam B&W Dutch Oven Boiler (1939)	5,900 kg/hr (dry wood) Semi-continuous Feed	52.7 wt.% dry solids 8,953 Btu/lb dry solids	None	899°C (secondary chamber)	--	13.0 (baghouse inlet)
ISW-A	18 MMBtu/hr (input) Kelly Model 2500 Controlled Air Incinerator (1981)	1,083 kg/hr (total feed) batch feed	5 waste materials in feed	0.03 cmh No. 2 oil (Runs 03, 04 only)	809°C (secondary chamber)	730°C (primary chamber)	11.3 (boiler outlet)

(Continued)

TABLE 5-12. MEAN COMBUSTION DEVICE OPERATING PARAMETERS DURING THE TEST RUNS (Continued)

Source Category/ Test Site	Combustion Device Type	Process Feed Rate	Feed Characteristics	Auxiliary Fuel Firing Rate(s)	Process Temperatures		Oxygen (% O_2)[a]
					Maximum	Other	
Metals Recovery							
MET-A	Cupola Furnace	43,400 kg/hr batch feed	22.1 wt.% telephone scrap; 8.0 wt.% copper-bearing telephone scrap; 26.5 wt.% copper-bearing residues; 9.1 wt.% plant reverts; 34.3 wt.% slag reverts; all on coke-free basis	6,450 kg/hr Coke	877°C (cupola roof)	--	20.2 (stack breeching)
WRI-A (wire only)	545 kg/hr wire United Model G-466 Wire Reclamation Incinerator (1978)	363 kg/hr (total feed) batch feed	12.5 wt.% combustible materials: 100% from wire	36 cmh natural gas	1054°C (afterburner outlet)	566°C (primary chamber)	5.7 (afterburner outlet)
WRI-A (wire & transformers)	545 kg/hr wire United Model G-466 Wire Reclamation Incinerator (1978)	314 kg/hr (total feed) batch feed	19.8 wt.% combustible materials: 29% from wire, 71% from transformers	36 cmh natural gas	1000°C (afterburner outlet)	558°C (primary chamber)	7.4 (afterburner outlet)
Miscellaneous Sources							
DBR-A	4 MM Btu/hr (input) ECO Model 100 drum & barrel reclamation incinerator (1974)	120 drums/hr semi-continuous	Drums containing lacquer & organic solvents, inks, enamel-type paint and orange juice	195 cmh natural gas	827°C (afterburner outlet)	588°C (primary chamber)	13.5 (afterburner outlet)
CRF-A	2060 kg/hr spent carbon (bare carbon basis) multiple hearth furnace (7 hearths, 1980)	1080 kg/hr (bare carbon)	Spent activated carbon from industrial wastewater treatment	None	953°C (hearth)	(afterburner outlet temperatures are considered propietary by plant)	13.9 (afterburner outlet)

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[a] Excess oxygen data for the black liquor boilers were obtained from plant-maintained in-situ oxygen monitors. Oxygen concentrations from this type of instrument are on a wet basis. Excess oxygen data for the other source categories were obtained by Radian using an extractive-type oxygen monitoring system. Oxygen concentrations from the extractive-type system are on a dry basis.

NA = data not available

TABLE 5-13. SUMMARY OF CONTROL DEVICE OPERATING PARAMETERS FOR SEWAGE SLUDGE INCINERATORS

Source Category/ Test Site	Pollution Control Device(s)	Flue Gas Flowrate thru Control Device (dscmm)	Pressure Drop Across Control Device (kPa)	Scrubber Liquid:Gas Ratio (m^3/dscm)	Scrubber Temperature		Particulate Removal Efficiency (%)
					Inlet (°C)	Outlet (°C)	
Sewage Sludge Incinerator							
SSI-A	Precooler	94	NA	--	NA	NA	NA
	Venturi-Impingement Scrubber		5.9	0.032	405	26	NA
SSI-B	Quad Cyclone	582	1.2	--	649^a	NA	72^a
	Precooler		0.01^a	NA	254^a	82	NA
	Venturi Scrubber		6.2	0.006^b	82^a	71^a	99^a
	Subcooler		1.2	--	71^a	21.4^a	NA
SSI-C	Precooler	798	NA	--	444	NA	--
	Impingement-Scrubber		2^a	0.007	NA	22	--

[a] Design data from plant
[b] Combined for Venturi and subcooler
NA = Data not available

TABLE 5-14. SUMMARY OF CONTROL DEVICE OPERATING PARAMETERS FOR BLACK LIQUOR BOILERS

Source Category/ Test Site	Pollution Control Device	Flue Gas Flowrate thru Control Device (acmm)	Design Particulate Removal Efficiency[a] (%)	ESP Temperature Inlet (°C)	ESP Temperature Outlet (°C)	ESP Specific Collection Area (m^2/acmm)
Black Liquor Boilers						
BLB-A	Wet Bottom ESP	8045	99.0	178	175	0.20
BLB-B	Dry Bottom ESP	8200	99.6	164	157	0.13
BLB-C	Dry Bottom ESP	8400	NA	156	146	NA

[a] Design as rated by manufacturer
NA = Data not available

TABLE 5-15. SUMMARY OF CONTROL DEVICE OPERATING PARAMETERS FOR WOOD COMBUSTION, METALS RECOVERY AND MISCELLANEOUS SOURCE CATEGORIES

Source Category/ Test Site	Pollution Control Device	Flue gas flow rate through control device (acmm)	Control device pressure drop (kPa)	Inlet Temperature °C	Outlet Temperature °C	Baghouse air:cloth ratio $\frac{\text{acmm gas}}{\text{m}^2\text{ bag area}}$	Afterburner Design Residence Time (second)	Afterburner Fuel Usage (Million Btu/hr)
Wood Combustion								
WFB-A	Multiclone	86720	NA	NA	NA	--	--	--
	Baghouse	86720	3.4	251	224	1.3	--	--
ISW-A	#2 fuel oil-fired Afterburner with refractory lined duct	408	--	730	809	--	1.0	NA
Metals Recovery								
MET-A	Natural Gas-fired Afterburner	8400[a]	--	NA	877	--	NA	NA
	Baghouse #1	7668	1.4	142	103	0.3[b]	--	--
	Baghouse #2	4840	2.1	130	103	0.3[b]	--	--
WRI-A	Settling Chamber	16[a]	NA	563	324	--	--	--
	Natural Gas-fired (W)[c]	16[a]	--	324	1,054	--	NA	1.2
	Afterburner (W&T)[d]	16[a]		324	1,000	--	NA	1.2
Miscellaneous Sources								
DBR-A	Natural Gas-fired Afterburner	193[a]	--	588	827	--	NA	6.9
CRF-A	Natural Gas-fired Afterburner	250[a]	--	proprietary	953	--	0.5	NA
	Spray Cooler	250[a]	NA	927	204	--	--	--
	Baghouse	997	1.4	204	177	NA	--	--

[a] Flowrate reported as dscmm.
[b] Design air:cloth ratio
[c] Wire only
[d] Wire and transformers
NA = data not available

5.7 ASH SAMPLING DATA

Table 5-16 summarizes the PCDD/PCDF content of ash samples collected at the Tier 4 test sites. These data are discussed below for each source category grouping.

Sewage Sludge Incinerators

For all three sewage sludge incinerators 2378-TCDD was not detected in the bottom ash. Total PCDD and total PCDF were not detected at Site SSI-A, and each were no more than 70 ppt at Sites SSI-B and SSI-C. At Site SSI-C, filterable solids from the scrubber water and the filtrate were analyzed separately. The filterable solids did not contain detectable quantities of 2378-TCDD, but 0.7 ng/liter of total PCDD and 13 ng/liter of total PCDF were detected. The filtrate contained much less PCDD/PCDF; 2×10^{-5} ng/liter of total PCDD and 3×10^{-4} ng/liter of total PCDF were detected.

Black Liquor Boilers

The ESP ash was sampled and analyzed only at Site BLB-C. At Site BLB-A, particulates were controlled with a wet bottom ESP; therefore ash samples could not be collected. At site BLB-B, particulates were controlled with a dry bottom ESP but there was no accessible ash sampling location. The ESP ash at Site BLB-C did not contain detectable quantities of 2378-TCDD, but contained 20 ppt of total PCDD and 20 ppt of total PCDF.

Wood Combustion

The bottom ash and baghouse dust from Site WFB-A and the bottom ash from Site ISW-A were analyzed for PCDD/PCDF.

The baghouse dust from WFB-A contained 100 ppt of 2378-TCDD, 1.1×10^6 ppt of total PCDD and 3.2×10^5 ppt of total PCDF. The bottom ash from the primary chamber and secondary chamber of boiler WFB-A were analyzed separately. Furans were not detected in either bottom ash. However, 150 ppt of PCDD's were detected in the primary chamber bottom ash and 100 ppt of PCDD's were detected in the secondary chamber bottom ash.

For Site ISW-A, the bottom ash contained 140 ppt of 2378-TCDD, 1.4×10^5 ppt of total PCDD and 7,400 ppt of total PCDF.

TABLE 5-16. SUMMARY OF ASH SAMPLE PCDD/PCDF DATA FOR THE TIER 4 TEST SITES

			PCDD/PCDF Content of Sample (ppt)		
Source Category	Site	Ash Sample Type	2378-TCDD	Total PCDD	Total PCDF
Sewage Sludge Incinerators	SSI-A	Bottom Ash	ND	ND	ND
	SSI-C	Bottom Ash	ND	20	70
		Scrubber water filterable solids (ng/l)	ND	0.7	13
		Scrubber water filtrate (ppt)	ND	0.3	4.0
		(ng/l scrubber water)	ND	2×10^{-5}	3×10^{-4}
	SSI-B	Bottom Ash	ND	10	50
Black Liquor Boilers[a]	BLB-C	Dry bottom ESP Ash	ND	20	20
Wood Combustion	ISW-A	Bottom Ash	140	138,200	7,400
	WFB-A	Bottom Ash - Primary	NR	150	ND
		Bottom Ash - Secondary	NR	100	ND
		Baghouse Dust	100	1,143,600	315,600
Metals	WRI-A	Bottom Ash - Primary			
		Wire Only	20	240,000	730,000
		Wire & Transformer	ND	19,500	82,000
		Settling Chamber			
		Wire Only	20	521,000	2,610,300
		Wire & Transformer	6	231,000	657,600
	MET-A	Baghouse Dust	150	106,600	571,700
Miscellaneous	CRF-A	Baghouse Ash	ND	110	50

---

[a] At Site BLB-A, particulates were controlled with a wet bottom ESP; therefore, ash samples could not be collected. At Site BLB-B, the dry bottom ESP did not have an accessible ash sampling location.

For Site DBR-A, contamination prevented meaningful and valid results.

DBR = Drum and barrel incinerator
SSI = Sewage sludge incinerator
BLB = Black liquor boiler
ISW = Industrial solid waste incinerator
WFB = Wood-fired boiler
WRI = Wire reclamation incinerator
CRF = Carbon regeneration furnace

Metals Recovery

Bottom ash and settling chamber ash were sampled at Site WRI-A at two feed conditions: wire-only feed and wire and transformer feed. For the wire-only feed condition, the bottom ash contained 20 ppt of 2378-TCDD, 2.4×10^5 ppt of total PCDD and 7.3×10^5 ppt of total PCDF. The settling chamber ash contained 20 ppt of 2378-TCDD, 5.2×10^5 ppt of total PCDD and 2.6×10^6 ppt of total PCDF.

For the wire and transformer feed condition, the bottom ash did not contain detectable quantities of 2378-TCDD. However, 19,500 ppt of total PCDD and 82,000 ppt of total PCDF were detected. The settling chamber ash contained 6 ppt of 2378-TCDD, 2.3×10^5 ppt of total PCDD and 6.6×10^5 ppt of total PCDF.

At Site MET-A, the baghouse dust contained 150 ppt of 2378-TCDD, 1.2×10^5 ppt of total PCDD and 5.7×10^5 ppt of total PCDF.

Miscellaneous Combustion Sources

The baghouse ash at Site CRF-A was analyzed. The baghouse ash did not contain detectable quantities of 2378-TCDD. However, 1.1×10^5 ppt of total PCDD and 5.7×10^5 ppt of total PCDF were detected.

5.8 AMBIENT AIR SAMPLING DATA

Table 5-17 summarizes the in-plant ambient air PCDD/PCDF concentration data developed for the four Tier 4 test sites for which samples were taken and analyzed (Sites MET-A, DBR-A, SSI-C, and CRF-A). Samples were also taken at Sites ISW-A and BLB-C but these samples were not analyzed.

No 2378-TCDD was detected in the ambient samples from any of the four sites for which data were available. Ambient total PCDD concentrations ranged from just above detectable at Site CRF-A and Site SSI-C (0.02 ng/dscm) to about 0.4 ng/dscm at Site DBR-A. Ambient total PCDF concentrations were considerably higher, ranging from 0.04 ng/dscm at Site CRF-A to 5.3 ng/dscm at Site DBR-A.

TABLE 5-17. SUMMARY OF AMBIENT PCDD/PCDF DATA FOR THE TIER 4 TEST SITES

	Ambient PCDD/PCDF Concentration (ng/dscm)		
Site[a]	2378-TCDD	Total PCDD	Total PCDF
MET-A[b]	NR	0.15	1.1
DBR-A[c]	ND (0.03)	0.39	5.3
CRF-A[d]	ND (0.1)	0.02	0.04
SSI-C	ND (0.0004)	0.23	0.16

[a] Ambient air sampling was performed at Sites ISW-A and BLB-C but the samples were not analyzed.

[b] Ambient air samples at Site MET-A were taken in the vicinity of the dilution air intake damper.

[c] Ambient air samples at Site DBR-A were taken in the vicinity of the furnace exit location.

[d] Ambient air samples at Site CRF-A were taken in the vicinity of the spray cooler air atomizer intake.

ND = Not detected at specified limits of detection.

NR = Not reported due to large quantities of native CDD's and CDF's which interfered with the isomer-specific analysis.

CHAPTER 6
DATA ANALYSIS

As discussed in Chapters 1 and 2, the primary purpose of the Tier 4 program was to address the questions: Do combustion sources emit CDD's? If so, how much? These questions have been largely answered by the results of the literature review and the stack testing program. A secondary objective of the Tier 4 program was to attempt to address some other questions including: What factors affect PCDD/PCDF emissions? How effective are conventional control devices for controlling PCDD/PCDF emissions?

This chapter will address these questions using statistical analysis of the stack gas data and subjective assessments. Statistical analysis of the ash data as well as correlations between ash samples and stack samples are presented in Chapter 8. The statistical analysis is presented in Section 6.1, and subjective assessments of the data are presented in Section 6.2. A discussion of PCDD/PCDF homologue distributions is presented in Section 6.3, and control of PCDD emissions is considered in Section 6.4.

6.1 FACTORS AFFECTING CDD/CDF EMISSIONS

Based on the literature review, there are many variables that have been hypothesized to affect CDD emissions. These are listed in Table 6-1. In addition to determining PCDD/PCDF emissions, the Tier 4 sampling program was designed to gather information on these variables or on surrogates for these variables so that the PCDD/PCDF formation hypotheses and factors affecting emissions could be tested. Data sets from seven other test sites were found in addition to the 13 Tier 4 test sites with sufficient information to be included in the statistical analysis. Other emission data sets reported in the literature did not contain sufficient information on feed characteristics, combustion temperatures, and combustion parameters (i.e., CO, O_2, etc.) to be included in the analysis. Average emissions and operating data were used from each site. A complete listing of the data matrix used in the statistical

TABLE 6-1. TIER 4 SURROGATE MEASUREMENTS FOR FACTORS AFFECTING DIOXIN EMISSIONS

Factors Affecting Dioxin Emissions	Variable or Surrogate Variable Measured in the Tier 4 Program
PCDD in feed	None (some feed samples archived for potential PCDD analysis)
Precursors in feed	Chlorobenzenes, chlorophenols, PCB's and TOX in feed
Chlorine in feed	Chlorine in feed and HCl emissions
Combustion temperature	Combustion chamber temperature or flue gas temperature
Residence time	Not measured, no surrogate
Oxygen availability	O_2 content of stack gas, CO emissions, THC emissions
Feed processing	Broad characterizations of feed types, moisture content of feeds (if appropriate), feed rate
Supplemental fuel	Fuel flow and heat input recorded, if available

NOTE: TOX = total organic halogen content of feed
THC = total hydrocarbon concentration in flue gas

analysis is given in Table 6-2. The data sets included in the matrix are identified in Table 6-3.

The remainder of this section presents an analysis of the factors affecting the magnitude of CDD/CDF emissions from combustion sources. The results of a rank order statistical analysis of the Tier 4 data are considered first, followed by a discussion of the sewage sludge incinerator, black liquor boiler and municipal solid waste combustor data.

6.1.1 Rank Order Statistical Analysis

A non-parametric "rank order" statistical analysis was performed on the Tier 4 data base in an attempt to determine the factors affecting CDD/CDF emissions. Rank order statistics investigate associations between variables by looking at the relative ordering (i.e., ranking) of the variables rather than their absolute magnitudes.

Parametric statistics based on magnitudes were not used as a starting point in the data analysis because non-parametric rank-order statistics were considered to be more valid for the existing data base. Key considerations are as follows:

- Conventional parametric statistics (Pearson product-moment correlations) assume a bivariate normal population. Because of the limited number of test sites in the data base and the wide range of CDD/CDF emissions found, the data are not well distributed across all possible values of variables (e.g., emissions from Site MET-A are more than an order of magnitude higher than those from the next highest site).
- Rank order non-parametric statistics (Spearman rank correlations) assume a continuous bivariate population, with no assumption of normality. Thus, the non-parametric tests require fewer assumptions about the distribution of the population being considered. In addition, there is no minimum sample size required for most non-parametric methods to be valid and reliable. Finally, the non-parametric tests provide an adequate means of treating non-detectable analytical values (they are treated as "ties").

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TABLE 6-2. DATA MATRIX FOR STATISTICAL ANALYSIS[a]

SITE#	OBS	TOTCL	MAXTEMP	COMBTEMP	CO	NOX	THC	TOTHCL	OUTTEMP	TOX
1	1.000	605.700	1438.000	795.000	2473.000	465.300	152.300	.	172.900	0.000
2	2.000	9668.000	1793.000	1479.000	370.000	128.300	7.200	10700.000	330.600	12.700
3	3.000	241.000	1596.000	1152.000	4677.000	788.000	22.700	.	170.700	0.000
4	4.000	896.000	2100.000	2100.000	136.000	83.200	3.500	107.000	343.900	0.000
5	5.000	5330.000	2100.000	2100.000	10900.000	42.600	57.700	2.500	314.700	0.000
6	6.000	201.000	1948.000	1050.000	4657.000	89.200	276.500	1316.000	1205.600	201.000
6	7.000	269.300	1832.000	1037.000	5605.000	126.100	877.500	537.000	1205.600	74.800
7	8.000	1878.600	1650.000	669.000	273.000	0.300	1.900	307.000	435.300	.
8	9.000	3350.000	2100.000	311.000	862.000	40.900	23.000	263.000	294.600	0.000
9	10.000	6412.600	1840.000	.	89.000	.	3.000	3.300	339.500	154.000
10	11.000	4303.000	1610.000	1610.000	30800.000	940.000	371.000	59.700	212.100	4303.000
11	12.000	4663.800	1520.000	1090.000	234.000	131.000	5.600	95.000	1314.400	802.000
12	13.000	295.000	1366.000	831.000	3112.700	419.000	.	.	92.900	0.000
13	14.000	87.100	.	.	36900.000	.	49500.000	.	.	.
14A	15.000	.	1817.000	1723.000	531.300	244.500	10.600	324.500	.	.
14B	16.000	.	1983.000	1813.000	582.000	218.400	9.900	586.400	.	.
15A	17.000	.	1868.000	1663.000	88.100	407.400	1.000	.	.	.
15B	18.000	.	1868.000	1632.000	48.800	360.000	1.100	.	.	.
15C	19.000	.	2108.000	1972.000	43.900	334.600	1.100	.	.	.
15D	20.000	.	1688.000	1437.000	67.500	377.100	[illegible]			

Site $ = Site number
TCDD2378 = ng/m^3 2378TCDD observed
TOTCL = total chloride content of feed materials (ppm); MAXTEMP = maximum temperature of combustion device °F)
COMBTEMP = primary chamber combustion temperature (°F); CO, NO$_x$, TCH = emission concentrations (ppmv @ 3% of O$_2$) of carbon monoxide, nitrogen oxides, and total hydrocarbons; TOTHCL = Outlet HCl/chloride emission concentration (mg/dscm @ 3% O$_2$); OUTTEMP = outlet sampling temperature (°F); TOX = total organic halide content of feed materials (ppm)

SITE#	TCDD2378	OTHTCDD	TOTPCDD	TCDF2378	OTHTCDF	TOTPCDF	[illegible]	IOTHCDD	ITOTCDD	I2378CDF	IOTHCDF	ITOTCDF
1	0.046	11.100	19.619	0.000	32.763	43.466	.	.	.	.	.	.
2	4.530	76.900	625.000	20.800	574.000	2390.000	.	.	.	.	.	.
3	0.000	0.399	1.595	2.125	19.000	27.600	.	.	.	.	.	.
4	0.000	0.020	0.750	0.000	0.155	0.574	0.000	0.007	1.790	0.000	0.321	1.470
5	0.000	0.000	1.191	0.009	0.131	0.706	0.000	0.000	17.100	0.042	0.187	1.050
6	0.138	1.200	173.000	0.553	12.800	305.000	.	.	.	.	.	.
6	0.126	1.050	704.000	0.913	44.800	866.000	.	.	.	.	.	.
7	0.279	47.300	195.000	1.770	37.400	83.200	0.873	21.500	102.000	5.860	100.000	154.000
8	0.000	0.127	2.940	0.005	0.461	2.110	0.000	1.100	9.000	0.000	5.430	15.100
9	0.000	0.570	3.690	0.000	1.200	3.320	0.091	2.440	28.800	1.390	20.200	70.100
10	232.000	1140.000	11900.000	5070.000	20600.000	60700.000	.	.	.	.	.	.
11	0.052	1.190	4.980	0.897	14.300	27.000	16.400	77.600	687.000	62.500	930.000	2170.000
12	0.142	8.120	52.700	54.300	150.000	446.000	.	7.760	101.000	76.700	133.000	455.000
13	.	.	.	.	.	.	.	.	.	.	.	.
14A	26.140	450.410	2533.550	44.870	935.280	2609.700	.	.	.	.	.	.
14B	16.710	449.740	6587.930	69.670	1048.910	6847.160	.	.	.	.	.	.
15A	.	6.850	220.930	.	48.060	293.850	.	.	.	.	.	.
15B	.	10.630	225.320	.	51.540	329.420	.	.	.	.	.	.
15C	.	2.110	99.570	.	19.010	150.980	.	.	.	.	.	.
15D	.	8.010	296.640	.	32.070	236.210	.	.	.	.	.	.

[a] PCDD/PCDF emission concentrations in units of ng/dscm @ 3% O$_2$; I indicates data for inlet location.

TABLE 6-3. STATISTICAL ANALYSIS INPUT DATA SOURCES

Observation Number in Table 6-2	Data Source/Test Site
1	Tier 4/SSI-A
2	Tier 4/ISW-A
3	Tier 4/SSI-B
4	Tier 4/BLB-A
5	Tier 4/BLB-B
6	Tier 4/WRI-A (wire only)
7	Tier 4/WRI-A (wire and transformers)
8	Tier 4/WFB-A
9	Tier 4/BLB-C
10	Tier 4/CRF-A
11	Tier 4/MET-A
12	Tier 4/DBR-A
13	Tier 4/SSI-C
14	Tier 4/WS-A
15	Ref 168/MWI 1
16	Ref 168/MWI 2
17	Ref 49/MWI, Normal operation
18	Ref 49/MWI, Long cycle
19	Ref 49/MWI, High temperature
20	Ref 49/MWI, Low temperature

For purposes of the analysis, the following combustion variables were considered to potentially affect or be related to the magnitude of CDD/CDF emissions: total chloride content of the feed, total organic halide (TOX) content of the feed, maximum combustion temperature, flue gas carbon monoxide concentration, flue gas total hydrocarbons (THC) concentration, and flue gas total chloride concentration. These data were available for the Tier 4 test sites, but were generally not available for the literature data. Dioxin/furan emissions from each site were characterized by flue gas concentrations of 2378-TCDD, other-TCDD, total PCDD, 2378-TCDF, other-TCDF, and total PCDF, corrected to 3% O_2.

Rank order correlations were developed between the combustion variables and three sets of flue gas PCDD/PCDF data. Outlet flue gas PCDD/PCDF concentration data were considered first, followed by the control device inlet data and a data set corresponding to the maximum PCDD concentration measured at each site (i.e., whether measured at the inlet or outlet location). Each of the data sets has advantages and limitations. The outlet flue gas PCDD/PCDF concentration data set is of particular interest because it represents actual emissions to the atmosphere and because these data are available for all test sites. A major disadvantage of the outlet data set is that effects of the control device are not taken into account by the combustion variables. This limitation is removed by looking at the control device inlet data set, but the number of test sites included in the inlet data set is much smaller. Also, several of the highest PCDD emitters are removed from consideration since inlet sampling was not performed at these sites (i.e., no inlet data were obtained for Sites MET-A, WRI-A, ISW-A). The maximum concentration data set has some advantages over both the outlet emissions data set and the control device inlet data set because 1) some of the control device effects are removed from the analysis, and 2) all of the test sites are represented in the data set. However, the maximum concentration data set has the disadvantage of including inlet data from some sites (i.e., sites for which inlet sampling was performed) and outlet data from other sites (i.e., sites for which outlet-only sampling was performed).

The data base used for the non-parametric tests is given in Table 6-2. A Spearman rank correlation matrix showing the association found between each pair of variables was developed. The association between variables is measured by the Spearman Rank Correlation Coefficient "R". Values of R larger than about 0.8 were considered to indicate a reasonable level of association between variables for this analysis.

The following observations can be made concerning the results of the rank order analysis.

Outlet Flue Gas Concentration Data

- Using the entire data base, there are strong associations between 2378-TCDD and total PCDD emissions (R = 0.93) and between 2378-TCDF and total PCDF (R = 0.93).
- Using only the Tier 4 data (except Site MET-A) there is a moderate association between flue gas total chloride concentration and total PCDD concentration (R = 0.73), and between flue gas total chloride concentration and total PCDF concentration (R = 0.8). However, when data from Site MET-A are included, the association becomes weaker since MET-A was characterized by extemely high PCDD emissions and relatively low flue gas total chloride concentrations.
- Other variables considered (i.e., maximum combustion temperature, CO, THC, total feed chloride, and TOX) did not show significant association with outlet PCDD/PCDF emissions.

Control Device Inlet Flue Gas Concentration Data

- Using all of the available inlet flue gas concentration data, there are strong inverse associations between maximum temperature and total PCDD (R = -0.85) and between maximum temperature and total PCDF (R = -0.93). However, this association may be misleading since one or more of the maximum temperatures listed in the data base occur downstream of the inlet location.
- Using all of the available inlet emissions data, there is a strong relationship between total PCDD and total PCDF (R = 0.86).

- Other variables considered (i.e., CO, THC, flue gas total chloride, and total feed chloride) did not show significant association with uncontrolled PCDD/PCDF emissions.

Maximum (Controlled, Uncontrolled) Emissions Data

- Using all of the available data there is a moderate association between TOX and Max PCDD (0.81) and between TOX and Max PCDF (0.81).
- Other variables considered (i.e., maximum combustion temperature, CO, THC, total feed chloride, and flue gas chloride) did not show significant association with Max PCDD/Max PCDF emissions.

As a whole, the statistical analysis did not provide quantitative relationships between CDD/CDF emissions and the independent variables considered. However, the analysis did identify a few potentially meaningful associations (e.g., PCDD vs. Max temp and TOX). Further investigation and testing are needed to confirm or refute the hypotheses suggested by the analysis.

6.2 Qualitative Observations

Table 6-4 gives an overall data comparison for the Tier 4 test sites, showing source characteristics, average inlet and outlet total PCDD emission concentrations, combustion characteristics, and feed characteristics. The test sites are ranked in order of the maximum average total PCDD emissions concentration measured at each site, regardless of whether it was measured at the inlet or the outlet location (i.e., Max PCDD). The purpose of the table is to provide a qualitative look at the factors affecting CDD emissions. Although simple comparisons are difficult to make in a data base of this complexity, a few observations can be made.

For example, sites with the highest PCDD emission concentrations (MET-A, WRI-A, DBI-A, and ISW-A) all contained significant quantities of organic chlorine in the feed, as measured by either the TOX procedure or the GC/MS precursor analysis. Conversely, sites with the lowest PCDD emission concentrations (SSI-A, BLB-B, BLB-C, BLB-A, and SSI-B) contained only trace quantities of organic chlorine in the feed. The wood-fired boiler (WFB-A) and one of the three sewage sludge incinerators (SSI-C) were unique in that no TOX

TABLE 6-4. DATA COMPARISON FOR THE TIER 4 TEST SITES (SOURCES RANKED BY MAXIMUM INLET/OUTLET PCDD EMISSION CONCENTRATION)

Test Site/Source Type	Emission Controls/ Outlet Temperature	PCDD Emissions (ng/dscm @ 3% O_2) Inlet	PCDD Emissions (ng/dscm @ 3% O_2) Outlet	Maximum Combustion Temperature	CO Emissions (ppmv @ 3% O_2)	HCl Emissions (mg/dscm @ 3% O_2)
MET-A: Secondary Copper Cupola Furnace	Afterburner (877°C) Baghouse (135°C)	---	11,900	877°C	31,000 ppmv	60
WRI-A: Wire Reclamation Incinerator (wire and transformer feed)	Afterburner (1000°C)	---	704	1000°C	5,600 ppmv	1,300
DBR-A: Drum and Barrel Incinerator	Afterburner (827°C)	687	5.0	827°C	234 ppmv	34
ISW-A: Industrial Solid Waste Incinerator	Afterburner (809°C)	---	625	809°C	370 ppmv	10,700
WFB-A: Salt-Laden Wood-Fired Boiler	Baghouse (224°C)	102	195	900°C	270 ppmv	295
WRI-A: Wire Reclamation Incinerator (wire-only feed)	Afterburner (1050°C)	---	173	1050°C	4,700 ppmv	860
SSI-C: Sewage Sludge Incinerator	Water Scrubber (22°C)	101	53	741°C	3,100 ppmv	---
CRF-A: Carbon Regeneration Furnace	Afterburner (953°C) Spray Dryer (204°C) Baghouse (204°C)	29	3.7	953°C	90 ppmv	4.2
SSI-A: Sewage Sludge Incinerator	Water Scrubber (26°C)	---	20	781°C	2,500 ppmv	---
BLB-B: Black Liquor Boiler	Direct Contact Evaporator Dry Bottom ESP (157°C)	17	1.2	---	10,900 ppmv	2.4
BLB-C: Black Liquor Boiler	Dry Bottom ESP (146°C)	9.0	2.9	---	3,100 ppmv	250
BLB-A: Black Liquor Boiler	Wet Bottom ESP (175°C)	1.0	0.8	---	140 ppmv	112
SSI-B: Sewage Sludge Incinerator	Water Scrubber (21°C)	---	1.6	869°C	4,700 ppmv	---

(Continued)

TABLE 6-4. DATA COMPARISON FOR THE TIER 4 TEST SITES (SOURCES RANKED BY MAXIMUM INLET/OUTLET PCDD EMISSION CONCENTRATION) (Continued)

Test Site	Feed Characterization				Auxiliary Fuel
	Feed Description	TOX ppm	Precursors	Total Chlorine	
MET-A	43,000 kg/hr metal-bearing feed				Natural Gas/AB
	22 wt% plastic-bearing copper scrap	4,300 ppm	0.3 ppm PCB	---	
	78 wt% other metallic scrap	---	---	---	
	15 wt% coke (not included in 100%)	---	ND	---	
WRI-A	314 kg/hr total feed				
	14.1 wt% transformer combustibles	23 ppm	0.2 ppm CP & PCBs	270 ppm	NG/AB 36 cmh
	5.7 wt% wire coating combustibles	201 ppm	trace CP	---	
DBR-A	120 drums/hr				
	Liquid residue (2.3 kg/drum)	802 ppm	ND-70 ppm CB	4,700 ppm	NG/AB
	Drum coating	---	ND-0.2 ppm CB	50.4 ppm	
ISW-A	1080 kg/hr total feed				
	64.8 wt% CPW	12.7[a] ppm	0.08 ppm PCP	9,670 ppm[a]	No. 2 fuel oil
	6.8 wt% treated wood	---	---	---	
	14.5 wt% painted wood	---	---	---	
	12.7 wt% WPP	12.7[a] ppm	10.6 ppm T, PCP	9,670 ppm[a]	
	0.6 wt% latex paint sludge	---	0.02 ppm PCP	---	
	0.6 wt% hytest paint sludge	---	0.01 ppm PCP	---	
	8.6 gph fuel oil	ND-22 ppm	ND	---	
WFB-A	11,200 kg/hr salt-laden logged wood	ND	ND	1,800 ppm	None
WRI-A	363 kg/hr coated wire				
	Wt% wire coating combustibles	201 ppm	trace CP	---	NG/AB
SSI-C	11,000 kg/hr sewage sludge (20% solids)	ND	ND-0.03 ppm CB	300 ppm	3,100
CRF-A	3,430 kg/hr solvent-laden spent activated carbon	154 ppm	0.16-6.6 ppm CB	6,400 ppm	
SSI-A	1,880 kg/hr sewage sludge (21% solids)	---	ND-0.01 ppm CB	600 ppm	No. 2 fuel Oil & digester gas
	No. 2 fuel oil	ND	---	35 ppm	
BLB-B	80,800 kg/hr strong black liquor	ND	trace CP	5,280 ppm	None
BLB-C	68,200 kg/hr strong black liquor	---	ND-0.01 ppm CP	3,350 ppm	No. 2 fuel Oil (Run 3 only)
	No. 2 fuel oil (Run 3 only)	ND	---	170 ppm	
BLB-A	82,900 kg/hr strong black liquor	---	ND-0.01 ppm CP	900 ppm	None
SSI-B	6,900 kg/hr sewage sludge (36% solids)	---	0.01-0.04 ppm CB	240 ppm	---

and only small quantities of precursors were detected, yet PCDD emissions were relatively high. This indicates that while TOX and/or precursor analyses may be useful as screening tools in identifying potential PCDD emission sources, they cannot be used alone as quantitative predictors of PCDD emissions. The relatively high levels of total chloride found at the high and low ends of the PCDD emissions spectrum indicate that total chloride analysis alone does not appear to be a useful indicator of PCDD emissions when comparing across source categories.

Further research is needed to improve state-of-the-art clean-up and extraction procedures for precursor and TOX analysis of complex feed materials such as those encountered in Tier 4. The analytical matrices of some of the samples analyzed (e.g., transformer combustibles from Site WRI-A) were very complex, and surrogate recoveries were low.

6.2.1 Qualitative Analysis for Sewage Sludge Incinerators

Table 6-5 gives a data comparison for the three sewage sludge incinerators tested in the Tier 4 program, including controlled CDD/CDF emissions per unit of feed, sludge characteristics, combustion characteristics, and incinerator and scrubber design parameters. The test sites are ranked in order of decreasing controlled total PCDD emissions from left to right across the page (i.e., SSI-C, SSI-A, SSI-B). Mass emission rate divided by sludge feed rate is used as the comparative emission parameter in Table 6-5 in order to remove the effect of incinerator size (i.e., feed rate) when comparing emissions from various test sites.

The data show a wide variation in CDD/CDF emissions between the three test sites, with average controlled total PCDD emissions ranging from 0.36 ug total PCDD emitted per kg of dry solids feed (i.e., ug/kg) for Site SSI-C to 0.005 ug/kg for Site SSI-B. Emissions from Site SSI-B are significantly lower than emissions from Sites SSI-A and SSI-C. The major difference in operations at Site SSI-B relative to SSI-A and SSI-C is the much higher solids content of the sludge (36 wt% solids for SSI-B vs. approximately 21 wt% solids for SSI-A and SSI-C). This allowed for autogenous sludge combustion, higher temperatures on the individual hearths, and also a higher exhaust gas temperature for the top hearth. In addition, the total chloride content of the sludge at Site SSI-B (660 ppm, dry basis) was much lower than that at

TABLE 6-5. DATA COMPARISON FOR THE THREE TIER 4 SEWAGE SLUDGE INCINERATOR TEST SITES

Parameter	SSI-C	SSI-A	SSI-B
Controlled Dioxin/Furan Emission Factors			
2378 TCDD	0.00094 ug/kg	0.00022 ug/kg	ND (0.0003 ug/kg)
Total PCDD	0.36 ug/kg	0.10 ug/kg	0.005 ug/kg
Total PCDF	3.0 ug/kg	0.23 ug/kg	0.083 ug/kg
Sludge Characteristics			
% Solids	20.3 wt %	21.1 wt %	36.2 wt %
% Volatiles	55.1 wt %	69.0 wt %	74.7 wt %
Total chloride content (dry)	1,500 ppm	2,800 ppm	660 ppm
Precursor content (dry basis)	ND - 0.15 ppm CB	ND - 0.05 ppm CB	0.03 - 0.1 ppm CB
Combustion Characteristics			
Maximum hearth temperature	741° C	781° C	869° C
Top hearth temperature	444° C	424° C	622° C
CO Emissions (dry)	3,100 ppmv	2,500 ppmv	4,700 ppmv
O_2 at top hearth (dry)	13.2%	11.9%	13.1%
Incinerator Design Characteristics			
No. hearths	12	6	9
Sludge Capacity (dry)	2,600 kg/hr	400 kg/hr	2,600 kg/hr
Scrubber Characteristics			
Scrubber Type	Impingement Tray	Venturi-Impingement Tray	Venturi
Outlet temperature	22°C	26°C	21°C
Liquid: Gas Ratio	0.007 m3/dscm	0.03 m3/dscm	0.006 m3/dscm

Sites SSI-A and SSI-C (2,000 ppm and 1,500 ppm, respectively). These factors may be responsible for the reduced CDD/CDF emissions at Site SSI-B.

Differences in other factors considered, such as precursor content of the sludge, CO emissions, excess air, incinerator size, and scrubber operation did not seem to affect the magnitude of CDD/CDF emissions.

6.2.2 Qualitative Data Analysis for Black Liquor Boilers

Table 6-6 gives a data comparison for the three black liquor boilers tested in the Tier 4 program. Included are total PCDD and total PCDF emissions per unit of feed, black liquor feed characteristics, combustion characteristics, boiler design parameters, and electrostatic precipitator design parameters. The data show that controlled total PCDD emissions per unit of feed ranged from about 0.3 x 10^{-2} ug PCDD per kg black liquor solids feed for Site BLB-A to 1.6 x 10^{-2} ug/kg for Site BLB-C. This represents a range of approximately a factor of 5.

The process data shown in Table 6-6 do not provide a simple explanation for the observed range of PCDD emissions. The three black liquor boilers had similar solids content in the feed (63 to 70 percent solids) and similar precursor characteristics (trace quantities of chlorophenols were detected for each site). Site BLB-A showed lower total chloride in the black liquor feed (1,400 ppm, dry weight basis) than Sites BLB-B or BLB-C (7,500 ppm and 5,300 ppm, respectively), which may account for the lower measured emissions. Combustion temperature data were not available for any of the black liquor boiler test sites.

6.2.3 Qualitative Data Analysis for Municipal Waste Incinerators

This section summarizes the municipal waste incinerator data base and presents an analysis of factors affecting PCDD and PCDF emissions from municipal waste incinerators (MWI's). The original focus of the analysis was to evaluate these emissions in light of key incinerator design and operating variables that may affect the formation and emission of PCDD's and PCDF's. The data base for the analysis consisted of MWI CDD/CDF emissions testing identified in the literature review. Unfortunately, complete operating and design data were often not obtained and/or reported for the MWI test sites in

TABLE 6-6. DATA COMPARISON FOR THE THREE TIER 4 BLACK LIQUOR BOILER TEST SITES

Parameter	BLB-C	BLB-B	BLB-A
Controlled Emissions per unit of feed			
Total PCDD	1.6×10^{-2} ug/kg	0.41×10^{-2} ug/kg	0.28×10^{-2} ug/kg
Total PCDF	0.79×10^{-2} ug/kg	0.24×10^{-2} ug/kg	0.21×10^{-2} ug/kg
Uncontrolled Emissions per unit of feed			
Total PCDD	2.5×10^{-2} ug/kg	5.9×10^{-2} ug/kg	0.63×10^{-2} ug/kg
Total PCDF	4.1×10^{-2} ug/kg	0.37×10^{-2} ug/kg	0.53×10^{-2} ug/kg
Black Liquor Characteristics			
% solids	63.1 wt %	70.3 wt %	65.0 wt %
Total chloride content (dry solids basis)	5,300 ppm	7,500 ppm	1,400 ppm
Precursor content (dry solid basis)	ND - 0.015 ppm CP	Trace CP	ND - 0.015 ppm CP
Combustion Characteristics			
CO emissions (dry basis)	862 ppmv	10,900 ppmv	136 ppmv
O_2 at boiler outlet (wet basis)	2.7 %	2.3 %	3.6 %
Total Cl emissions	250 mg/dscm @ 3% O_2	2.4 mg/dscm @ 3% O_2	112 mg/dscm @ 3% O_2
Boiler Design Characteristics			
Rated Capacity (TPD pulp)	850 tpd	800 tpd	900 tpd
Boiler type	Low odor	Direct contact	Low odor
Electrostatic Precipitator Characteristics			
Precipitator type	Dry bottom	Dry bottom	Wet bottom
Outlet gas temperature	146° C	157° C	175° C

the literature. However, by including information from several sources some common information was found for a few of the sites.

6.2.3.1 Description of the MWI Data Base. Thirty-eight articles were reviewed for information describing emissions testing for PCDD's and PCDF's at municipal waste incinerators. Of these, 28 studies contained sufficient data on CDD/CDF emissions, CDD/CDF fly ash content, and process operating characteristics to be useful in this data analysis. Table 6-7 summarizes CDD and CDF flue gas emissions data from nine MWI's located in the United States and Canada. Pertinent design and operating data are also summarized as available. An in-depth comparison of additional operating variables cannot be made since the data were not available for each of the tested units. Table 6-8 summarizes CDD and CDF flue gas emissions data from eight MWI's located in Europe. In addition, the literature review identified a facility in Tsushima, Japan, where MWI emissions testing had been performed.[51] However, the results of the emissions testing at the Tsushima facility were removed from this analysis because the test results have not been verified. The remaining studies in the literature were not used in the data analysis because these reports contained data reported elsewhere or because emissions data could not be reduced into suitable units for this analysis (e.g., in some cases data were reported as ng/sample). Data contained in the rejected studies were not entered into the literature data base. However, these studies and their reasons for rejection are presented in Table 6-9.

It is important to understand that the data used in this analysis are the "as-published" data. No adjustments were made to CDD and CDF concentrations reported in the literature to account for 1) unreported recovery efficiencies of surrogate compounds used in the analytical procedures, 2) incomplete analysis of the tetra- through octa-PCDD/PCDF homologues, or 3) variations in excess combustion air (i.e., excess air dilution). These limitations in the data base are discussed below.

Because of the complexity of PCDD/PCDF analysis, isotopically labeled internal standards (i.e., surrogate standards) are used to estimate actual recoveries of PCDD and PCDF isomers in each sample analysis. However, less than 5 percent of the emissions studies that were reviewed report surrogate

TABLE 6-7. DIOXIN AND FURAN EMISSION DATA SUMMARY FOR UNITED STATES AND CANADIAN MSW INCINERATORS

Facility Location (Facility Number)	Operating Capacity Tons/Day	Fuel Type	Emissions Control Device	Average Combustion Temp, °C	Average PCDD Emissions ng/m^3	Average PCDF Emissions ng/m^3	REF
1. Albany, NY (11)							
a. condition 1[a]	600	RDF	ESP	--	165.0	17.3	32
b. condition 1[b]	600	RDF	ESP	--	73.8	8.5	32
2. Charlottetown, P.E.I., Canada (20)							
a. condition 1[c]	42	MSW	Settling	1,000	107.0	143.0	49
b. condition 2[d]	42	MSW	hopper	1,000	103.0	156.0	49
c. condition 3[e]	45	MSW	"	1,130	62.0	95.0	49
d. condition 4[d]	41	MSW	"	900	123	98.0	49
3. Hampton, VA (35)							
a. (1983 tests)	125	MSW	ESP	810	2,300	11,000	92
b. (1981 tests)	125	MSW	ESP	--	4,200	7,400	174
c. (1982 tests)	125	MSW	ESP	--	245	384	101
d. (1984 tests)	125	MSW	ESP	810	5,950	8,300	205
4. Akron, OH (36)	600	RDF	ESP	--	174	458	101
5. Dyersburg, TN (38)	50	MSW	None	--	11.2	72.5	101
6. Philadelphia, PA							
(N.W. Unit 1) (46)	--	MSW	ESP	940	2,400	2,500	168
(N.W. Unit 2) (46)	--	MSW	ESP	990	1,333	1,066	168
7. Dayton, OH (48)	225	RDF	ESP	--	47.6	110.0	174
8. Canada (58)	270	RDF	ESP	700	2,680	--	181
9. Chicago, IL (59) (Northwest)	1,600	MSW	ESP	1,100	45	460	196

[a] condition 1 = with overfire natural gas

[b] condition 2 = without overfire natural gas

[c] condition 1 = normal operation (i.e., normal secondary chamber temperature)

[d] condition 2 = long feed cycle operation

[e] condition 3 = high secondary chamber operation

[f] condition 4 = low secondary chamber operation

[g] A combustion air preheater and a stack gas carbon monoxide monitoring system were installed in between the 1983 and 1985 tests at the Hampton facility.

NOTE: PCDD/PCDF concentrations in this table are at as-measured oxygen conditions.

TABLE 6-8. DIOXIN AND FURAN EMISSION DATA SUMMARY FOR EUROPEAN MSW INCINERATORS

Facility Location (Facility Number)	Operating Capacity Tons/Day	Fuel Type	Emissions Control Device	Average Combustion Temp, °C	Average PCDD Emissions ng/m^3	Average PCDF Emissions ng/m^3	REF
European Facilities							
1. Italy (13)	--	--	--	--	473	61.5	117
2. Italy (14)	--	--	ESP	--	49,000	7,900	117
3. Italy (15)	--	--	ESP	--	7,500	1,440	117
4. Italy (16)	--	--	ESP	--	4,410	3,600	117
5. Italy (17)	--	--	ESP	--	1,030	472	117
6. Italy (18)	--	--	ESP	--	588	51.0	117
7. Italy (33)							
a. Condition 1[a]	--	Dry MSW	ESP	--	269	397	118
b. Condition 2[b]	--	Wet MSW	ESP	--	7,360	6,910	118
8. Bevern, Belgium	--	MSW[c]	--	--	51.5	34.3	119

[a] condition 1: dry MSW
[b] condition 2: wet MSW
[c] Feed composition was 43 percent MSW, 57 percent light industrial waste.
Dash (--) indicates data were not reported.
NOTE: PCDD/PCDF concentrations in this table are at as-measured oxygen conditions.

TABLE 6-9. MWI EMISSION STUDIES NOT INCLUDED IN DATA BASE

Reference Number	Reason for Rejection
44	Flue gas emissions reported as ppb/sample, sample size unknown.
51	Dry repeat not published.
97	Flue gas emissions reported as ng/sample, sample size unknown.
142	Duplicate of reference 144 data.
148	It is not possible to determine which European facilities were tested. The report states that emissions testing was performed at "at least 25 facilities." Emissions are presented for facilities that were found to be lowest, average and highest emitters.
202	Duplicate of reference 203 data.
221	Dioxin and furan emissions were not contained in the report.
228	Emissions reported as ng/sample, sample size unknown.
243	Analysis for the presence of PCDD's and PCDF's was not performed on stack gas samples.

recovery values. Thus, there may be variability in the data base attributable to analytical procedure differences between the various laboratories represented in the literature studies.

In some studies flue gas and fly ash samples were analyzed for only specific homologues (most commonly the tetra- and octa-CDD and CDF homologues).[12,26,43,71,115] This is because isotopically-labeled standards for all of the CDD/CDF homologues have become available only recently. The emissions data contained in these studies are included in the analysis but no adjustments were made to specific homologue concentrations to obtain emission values representing total concentrations (i.e., all homologues) of PCDD's and PCDF's. Additionally, the 2378-TCDD and 2378-TCDF isomers are not routinely analyzed for in all samples. Less than 3 percent of the facilities tested report data for these isomers.[205,32,196,101,168]

Variations in excess combustion air between the test facilities affect the measured CDD/CDF concentration by both volumetric stack gas dilution and at the basic combustion level. Ideally, the volumetric stack gas dilution effect can be accounted for by correcting the data to a reference oxygen or carbon dioxide level (e.g., 3% O_2 or 12% CO_2). However, since oxygen or carbon dioxide concentration data were not reported for all test facilities, the data could not be uniformly treated. For this reason, none of the CDD/CDF emission concentration data were corrected to a reference oxygen level.

6.2.3.2 Rank Order Analysis of Flue Gas Emissions of CDD's and CDF's.

The focus of this section is to relate flue gas and fly ash emissions of CDD and CDF to key MWI design and operating parameters. As described in Chapter 4, many factors are believed to be responsible for the formation of CDD and CDF from municipal waste combustion. Two that were identified and are related, are feed composition and furnace temperature. This section will show that there is a possible relationship between furnace temperature, which is largely controlled by the heat content of the fuel, and flue gas emissions of PCDD's and PCDF's. However, this relationship is based on limited data. Less than 25 percent of the MWI emissions studies that were reviewed contain information describing both feed material or operating conditions.

Because many factors are involved in the formation of CDD's and CDF's from MWI's, the reaction mechanism and factors affecting the mechanism are not well understood. However, a convenient method to test which variables play a key role is a Rank Order plot. Table 6-10 summarizes the rank order of flue gas PCDD and PCDF emissions and combustion temperature for the seven MWI units in the data base for which both flue gas PCDD/PCDF emissions data and combustion temperature data are available. Figure 6-1 presents a rank order plot of flue gas emissions of PCDD's versus decreasing combustion temperature. The seven facilities included in the table and figure are all located in the United States and Canada. Figure 6-2 presents a similar Rank Order plot of flue gas emissions of PCDF's versus decreasing combustion temperature for 11 facilities located in North America, Europe and Japan. Figures 6-1 and 6-2 both indicate that ranked flue gas emissions of PCDD's and PCDF's increase with ranked decreasing furnace temperature.

Spearman rank correlation coefficients were computed for combustion temperature versus PCDD's (Spearman correlation coefficient = -0.99) and for combustion temperature versus PCDF's (Spearman correlation coefficient = -0.62). As discussed earlier, the Spearman rank correlation coefficient measures the degree of correspondence between variable rankings, instead of between actual variable values. However, it can still be considered a measure of association between samples and an estimate of the association between variables in a continuous bivariate population.

The hypothesis of no agreement between sets of rankings was tested for both PCDD and PCDF and was rejected at a significance level of 10 percent. Therefore, an inverse relationship exists between combustion temperature rank and PCDD and PCDF emission ranks. Thus, the data indicate that MWI facilities with high combustion temperatures tend to have lower CDD/CDF emissions than MWI facilities with low combustion temperatures.

Table 6-11 summarizes the rank order of fly ash PCDD content and combustion temperature for the 16 MWI units in the data base for which both fly ash data and combustion temperature data are available. Figure 6-3 presents a rank order plot of fly ash PCDD content versus decreasing furnace temperature. The plot indicates that no relationship exists between these two

TABLE 6-10. RANKING OF FLUE GAS EMISSIONS OF PCDD'S AND PCDF'S WITH FURNACE TEMPERATURE

FACILITY NUMBER	MWI LOCATION	OPERATING CAPACITY TONS/DAY	FUEL TYPE	EMISSIONS CONTROL DEVICE	AVERAGE COMBUSTION TEMP, °C	AVERAGE PCDD EMISSIONS ng/m³	AVERAGE PCDF EMISSIONS ng/m³	PCDD RANKING		PCDF RANKING		REFERENCE NO.
								HIGHEST TEMP	LOWEST EMISSIONS	HIGHEST TEMP	LOWEST EMISSIONS	
20	Charlottetown PEI, Canada	42	MSW	Settling Hoppers	1,000[a]	107	143	3	3	3	3	49
20	Charlottetown PEI, Canada	45	MSW	Settling Hoppers	1,130[b]	62	95	1	2	1	1	49
20	Charlottetown PEI Canada	40	MSW	Settling Hoppers	900[c]	123	98	5	4	5	2	49
35	Hampton, VA	125	MSW	ESP	810	11,000	2,280	7	9	7	6	92
46	N.W. Philadelphia (Unit 1)	--	MSW	ESP	990	2,370	2,530	4	6	4	7	168
46	N.W. Philadelphia (Unit 2)	--	MSW	ESP	990	745	775	4	5	4	5	168
58	SWARU, Ontario Canada	240	RDF	ESP	695	2,680	--	8	7	--	--	181
59	Chicago, N.W.	1,600	MSW	ESP	1,100	45	460	2	1	2	4	196
35	Hampton, VA	125	MSW	ESP	816	5,950	8,260	6	8	6	8	205

[a] Normal operation (secondary chamber temperature)

[b] High secondary temperature operation (secondary chamber temperature)

[c] Low secondary temperature operation (secondary chamber temperature)

-- = Data were not available

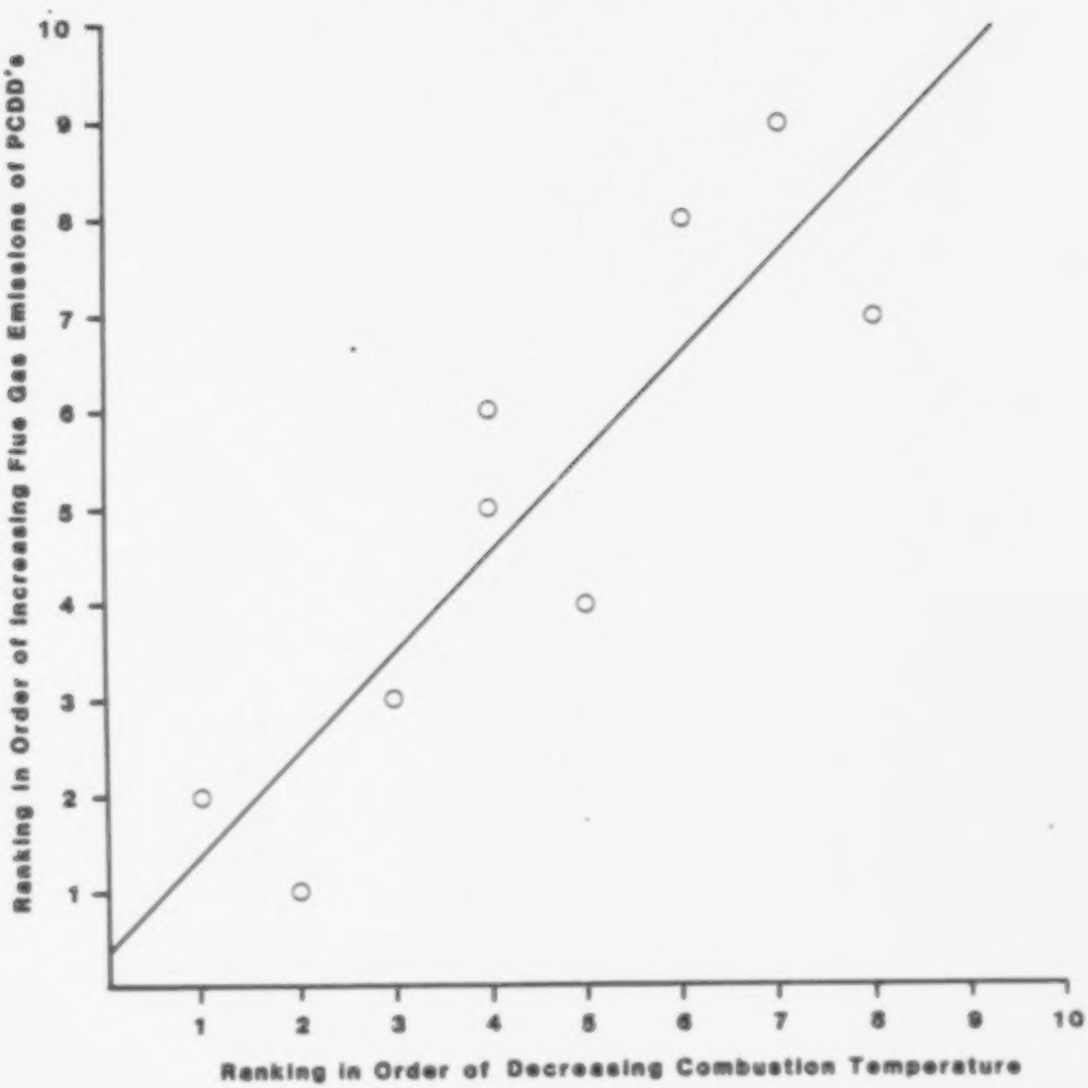


Figure 6-1. Rank Order Plot of PCDD Emissions vs. Combustion Temperature for Municipal Waste Incinerators (Data in Table 6-10)

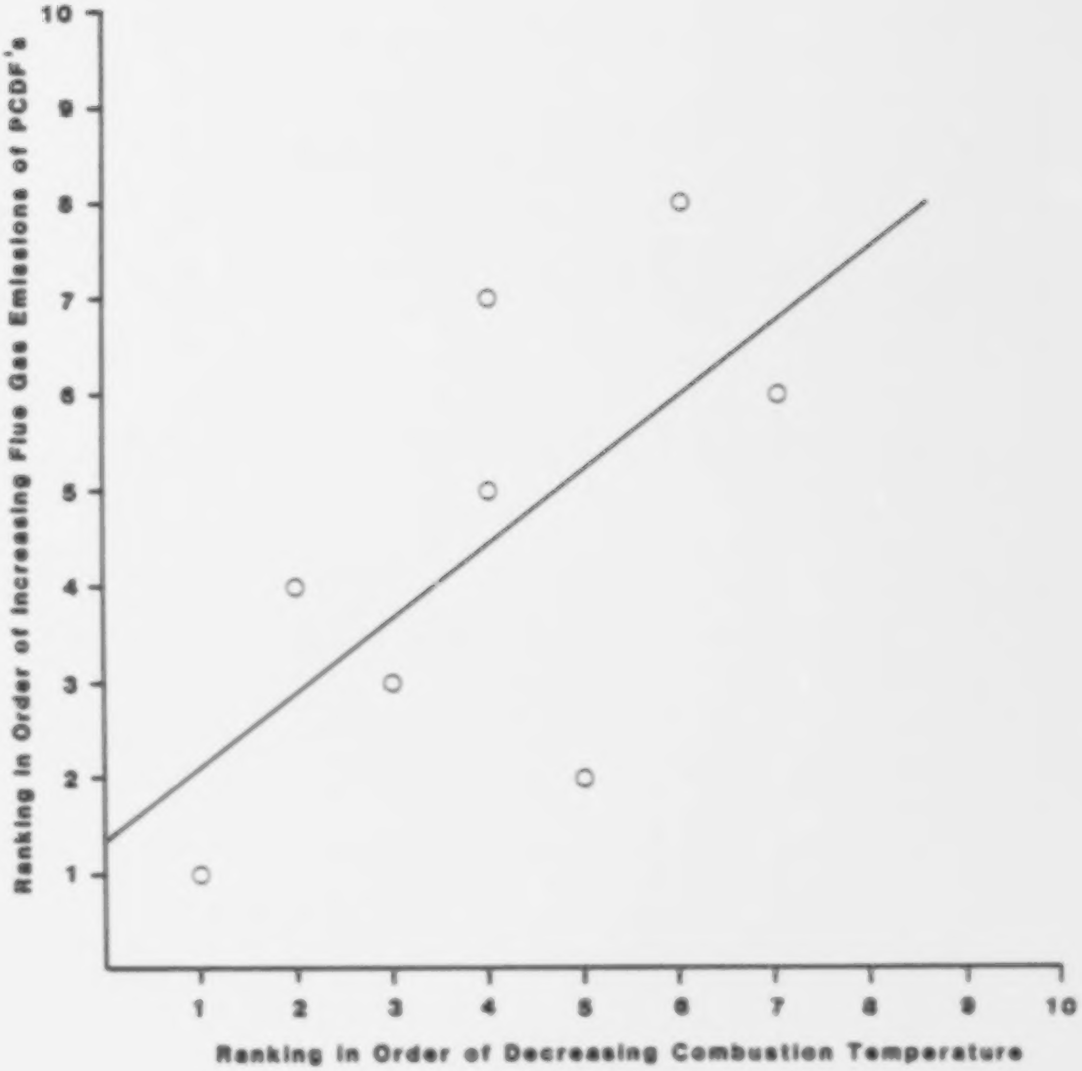


Figure 6-2. Rank Order Plot of PCDF Emissions vs. Combustion Temperature for Municipal Waste Incinerators (Data in Table 6-10)

TABLE 6-11. RANKING OF PCDD IN FLY ASH WITH FURNACE COMBUSTION TEMPERATURE

FACILITY NUMBER	MWI LOCATION	OPERATING CAPACITY TONS/DAY	FUEL TYPE	EMISSIONS CONTROL DEVICE	AVERAGE COMBUSTION TEMP, °C	AVERAGE PCDD ASH CONCENTRATIONS ng/g	PCDD RANKING HIGHEST TEMP	PCDD RANKING LOWEST EMISSIONS	REFERENCE NO.
20	Charlottetown, PEI, Canada	42	MSW	Settling Hoppers	1,000[b]	31	3	6	49
20	Charlottetown, PEI, Canada	45	MSW	Settling Hoppers	1,130[c]	72	1	7	49
20	Charlottetown, PEI, Canada	40	MSW	Settling Hoppers	900[d]	87	6	8	49
28	Southern Ontario, Canada	--	--	ESP	900	12[e]	6	4	71
29	Southern Ontario, Canada	--	--	ESP	900	9.3[e]	6	3	71
30	Japan	--	--	ESP	825	8.5[e]	7	2	71
31	Japan	--	--	ESP	825	4.8[e]	7	1	71
35	Hampton, VA	125	MSW	ESP	810	800	8	13	92
41	Paris, France	--	--	ESP	950	275	5	10	116
42	Paris, France	384	MSW[f]	ESP	950	293	5	11	118
42	Paris, France	384	MSW[g]	ESP	950	245	5	9	118
46	N.W. Philadelphia (Unit 1)	--	MSW	ESP	990	1,980	4	16	168
46	N.W. Philadelphia (Unit 2)	--	MSW	ESP	990	1,330	4	14	168
47	E.C. Philadelphia (Unit 1)	--	MSW	ESP	1020	1,900	2	15	168
47	E.C. Philadelphia (Unit 2)	--	MSW	ESP	1020	716	2	12	168
58	SWARU, Ontario, Canada	240	RDF[a]	ESP	695	22.9	9	5	181

[a] Refuse derived fuel (RDF), defined as MSW that was separated and pulverized
[b] Normal operation (secondary chamber temperature)
[c] High secondary temperature operation (secondary chamber temperature)
[d] Low secondary temperature operation (secondary chamber temperature)
[e] Fly ash samples analyzed only for presence of TCDD's
[f] Analysis indicates that feed contains 1 percent polyvinylchloride (PVC)
[g] Feed spiked with 300 percent of normal amount of PVC
-- = Data were not available

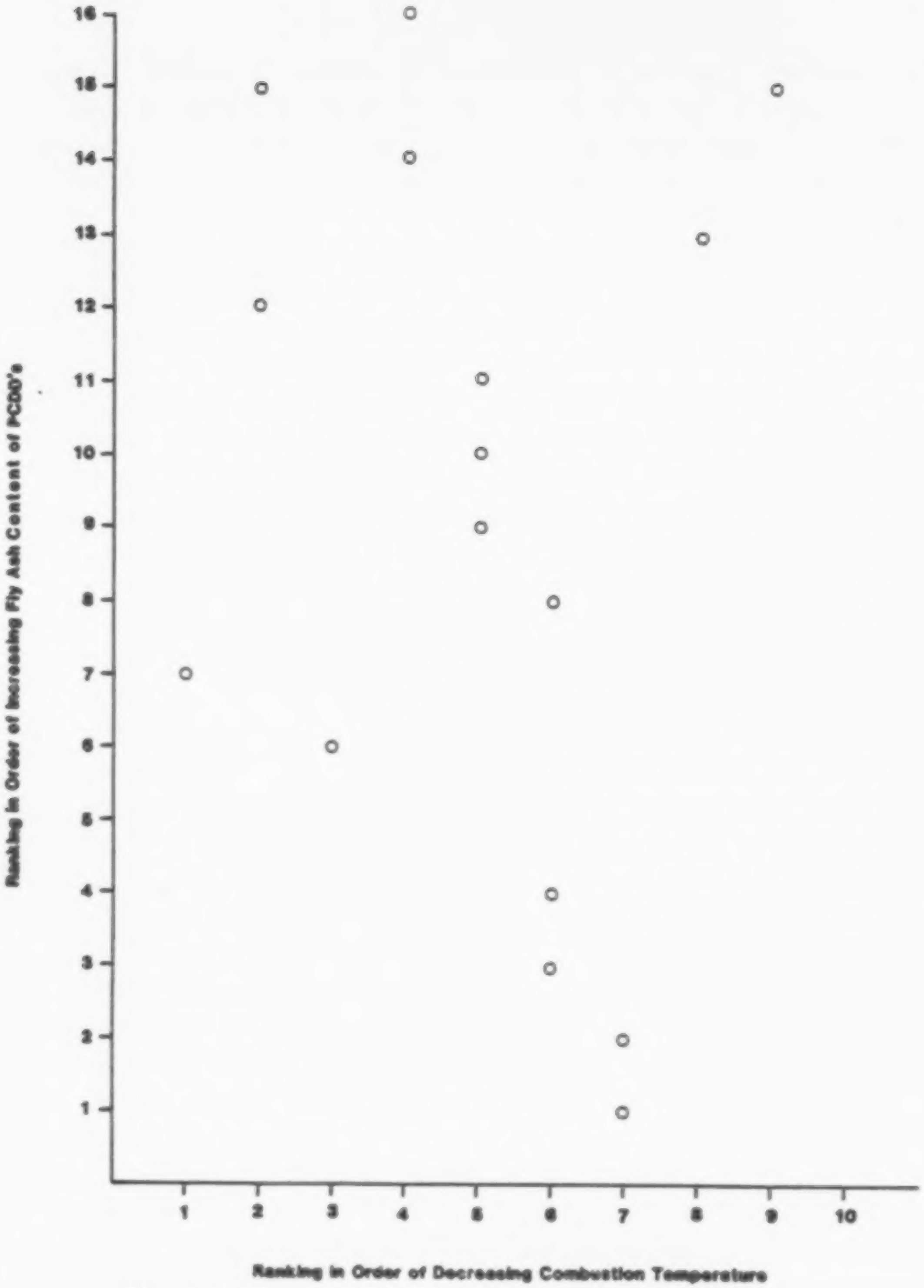


Figure 6-3. Rank Order Plot of Fly Ash PCDD Content vs. Combustion Temperature for Municipal Waste Incinerators (Data in Table 6-11)

variables. However, since the fly ash/combustion temperature data base listed in Table 6-11 contains facilities with potentially widely different designs and ash handling schemes, other factors such as temperature history of the ash may have obscured any possible relationship between fly ash PCDD content and combustion temperature.

6.2.3.3 Summary. The analysis presented in this section in conjunction with the literature review shows an association between two variables that may affect flue gas emissions of CDD's and CDF's from MWI's. These factors are summarized as follows:

1. Flue gas emissions of PCDD's and PCDF's appear to be inversely related to furnace temperature. Two factors that directly affect furnace temperature are excess air and the heat content of municipal waste fuels. Values of these parameters are not normally reported in emission test reports. However, the data suggest that there is a relationship between the heat content of fuels and the emissions of CDD and CDF's in flue gases. Elevated concentrations of PCDD's and PCDF's were found in the flue gas samples of two facilities located in Hampton, Virginia, and in northern Italy.[174,205,87] Emissions testing at both facilities was performed over a period of typical operation and when the feed was wet. Maximum CDD and CDF emission levels were reported to be approximately 10 times higher when the feed was wet during normal operating conditions (dry feed).[87] This also corresponds to periods of low combustion temperatures.
2. Higher levels of CDD's and CDF's are found in the flue gases of MWI's that were reported to have flawed incinerator design and suffer from poor maintenance. For example, the literature reports that the rear grate seals of a Canadian facility (Facility 181) fit poorly and permit undergrate air to by-pass the grates and enter the furnace at the rear wall. Furthermore, blockage of holes in the grates also results in poor distribution of combustion air into the (lower) furnace.
3. The PCDD and PCDF contents of fly ash from MWI's are not related to furnace temperature alone, but are probably a function of several

design and operating variables. In general, however, large concentrations of CDD's and CDF's in stack gases are accompanied by large concentrations of CDD's and CDF's in the fly ash.

4. PCDD and PCDF emissions levels reported for European facilities are higher than those for United States and Canadian facilities. Although these differences cannot be explained by this analysis, these differences may be due to emissions testing at facilities that were located in rural areas where a large proportion of the waste contains agricultural products such as vegetables. It may also reflect differences in incinerator design, incinerator age, sampling methodologies, analytical methodologies, or other factors.

6.3 PCDD/PCDF HOMOLOGUE DISTRIBUTIONS

This section presents a qualitative analysis of the PCDD/PCDF homologue distributions for the Tier 4 test sites. The purpose of the analysis is to determine whether a given test site or combustion source category has a characteristic homologue "signature."

Homologue distributions (mole fraction basis) of the inlet (i.e., upstream of the control device) and outlet (i.e., downstream of the control device) emissions from the Tier 4 test sites are shown in Figures 6-4 through 6-12. The test sites are grouped by source category to facilitate comparison between similar sites. Inlet and outlet data are presented on facing pages to facilitate comparisons between uncontrolled and controlled homologue distributions from each site. The average magnitude of total PCDD and total PCDF emission concentrations for each site are shown on the homologue distribution figures using the nomenclature PCDD and PCDF. The homologue distribution data are presented using the mole fraction basis because this is more relevant to a consideration of combustion chemistry than the mass fraction basis. The sum of the mole fractions for the various PCDD and PCDF homologues add up to 1.0 for each test run.

The following general observations can be made regarding the homologue distribution results:

SEWAGE SLUDGE INCINERATORS
INLET

Site SSI - A

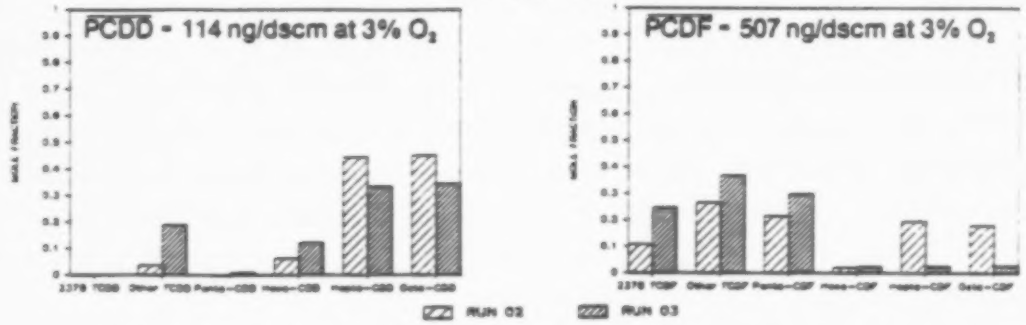
Analytical Data were not Reported by Troika for the Inlet MM5 Samples taken at Site SSI - A due to Unacceptable Surrogate Recovery Results

Site SSI - B

Uncontrolled Emissions from Site SSI - B were not Sampled

DIOXINS **FURANS**

Site SSI - C



Dioxin/Furan Homologue Distributions of Uncontrolled Emissions from Sewage Sludge Incinerators (Sites SSI - A, SSI - B, SSI - C)

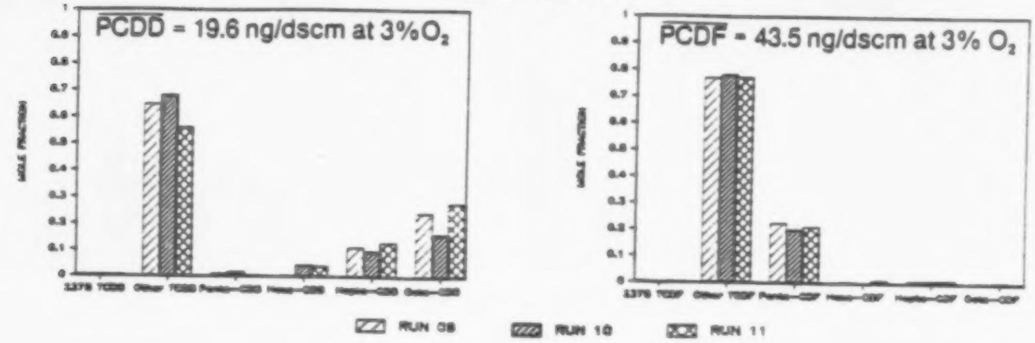
Figure 6 - 4.

SEWAGE SLUDGE INCINERATORS
OUTLET

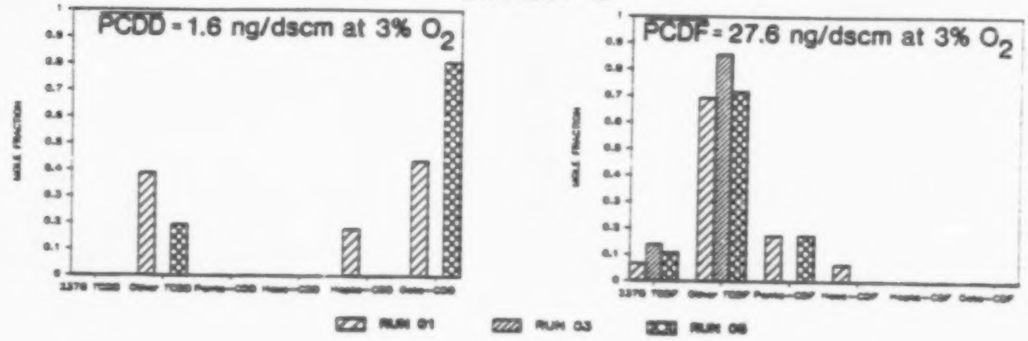
DIOXINS

FURANS

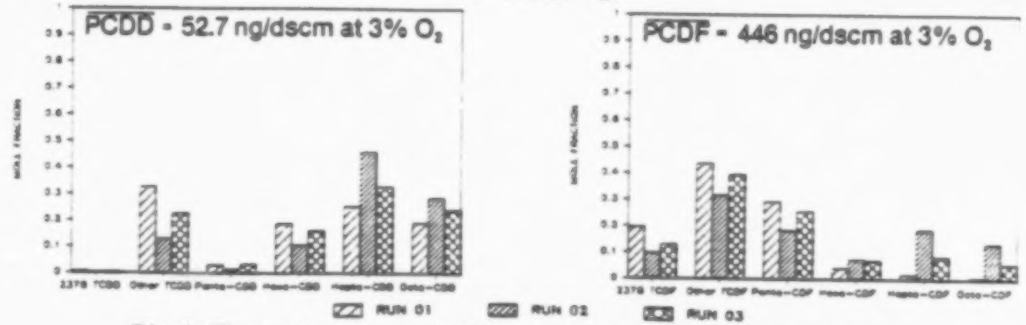
Site SSI - A



Site SSI - B



Site SSI - C



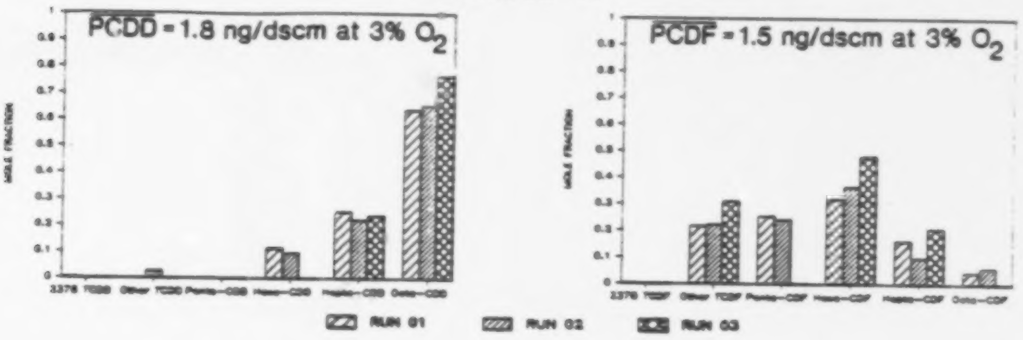
Dioxin/Furan Homologue Distibutions of Controlled Emissions from Sewage Sludge Incinerators (Sites SSI - A, SSI - B, SSI - C)

Figure 6 - 5.

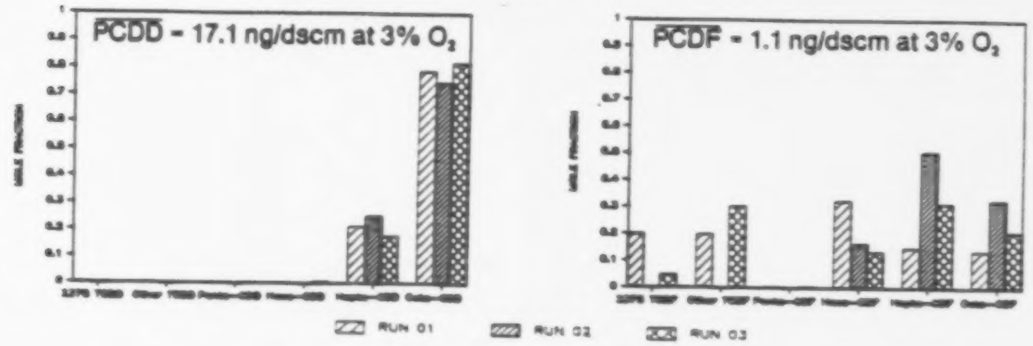
BLACK LIQUOR BOILERS/INLET

DIOXINS FURANS

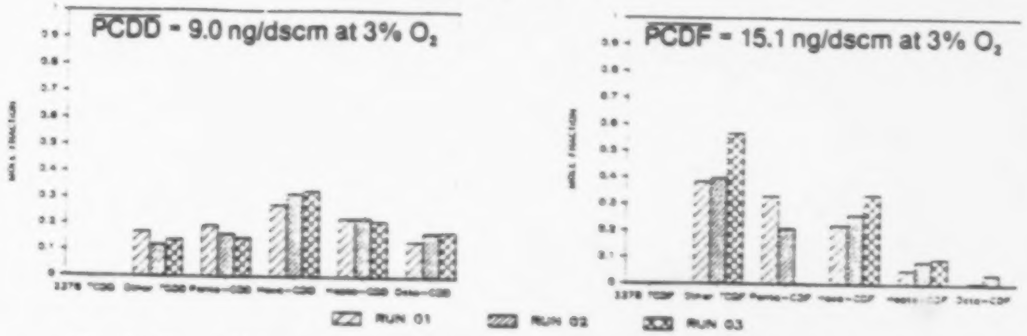
Site BLB - A



Site BLB - B



Site BLB - C



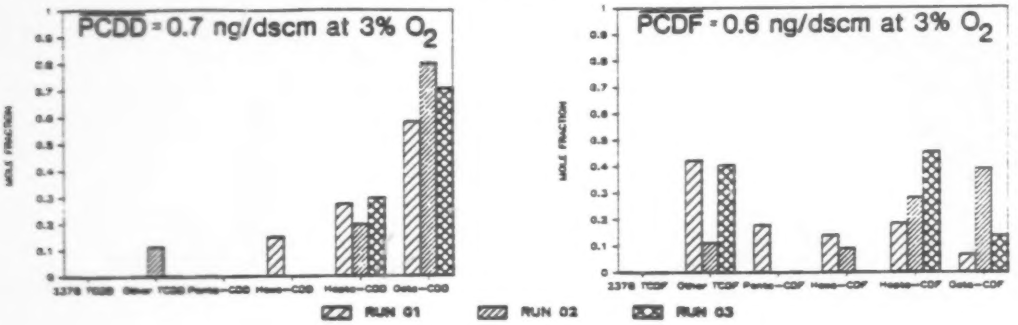
Dioxin/Furan Homologue Distributions of Uncontrolled Emissions
from Black Liquor Boilers
(Sites BLB - A, BLB - B, BLB - C)

Figure 6 - 6.

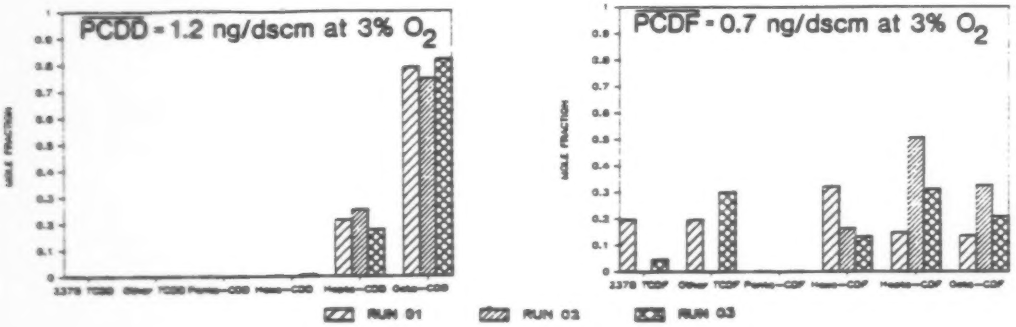
BLACK LIQUOR BOILERS/OUTLET

DIOXINS FURANS

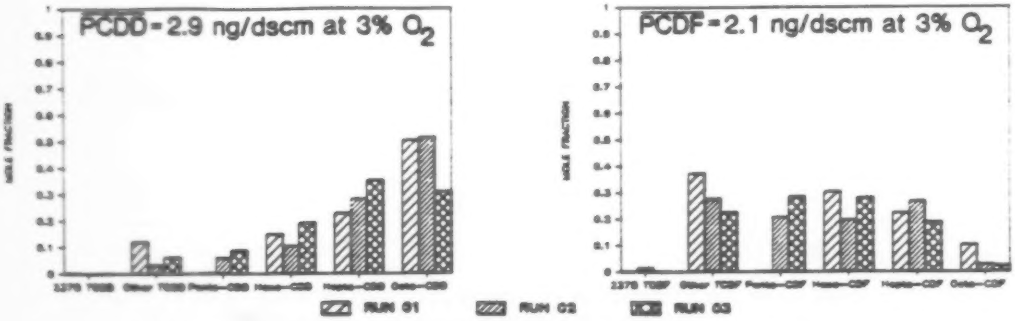
Site BLB - A



Site BLB - B



Site BLB - C



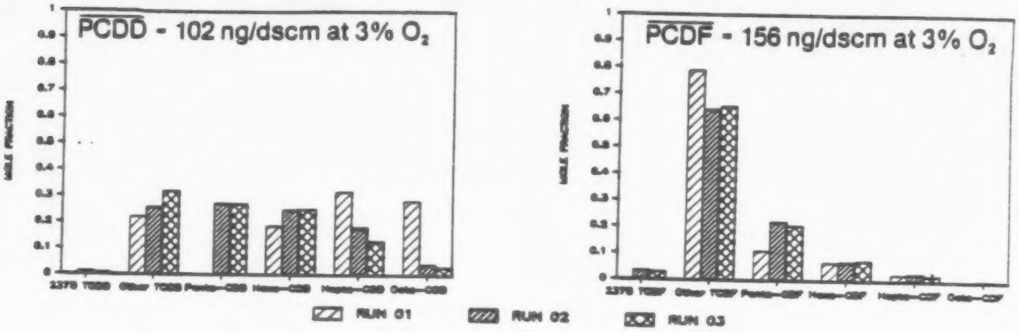
Dioxin/Furan Homologue Distributions of Controlled Emissions
from Black Liquor Boilers
(Sites BLB - A, BLB - B, BLB - C)
Figure 6 - 7.

WOOD COMBUSTION/INLET

DIOXINS

FURANS

Site WFB - A



Site ISW - A

Uncontrolled Emissions from Site ISW - A were not Sampled

Site WS - A

Analytical Data were not Reported by Troika for MMS Samples taken at Site WS - A due to Unacceptable Surrogate Recovery Results

Dioxin/Furan Homologue Distributions of Uncontrolled Emissions from Wood Combustion Processes (Sites WFB - A, ISW - A, WS - A)

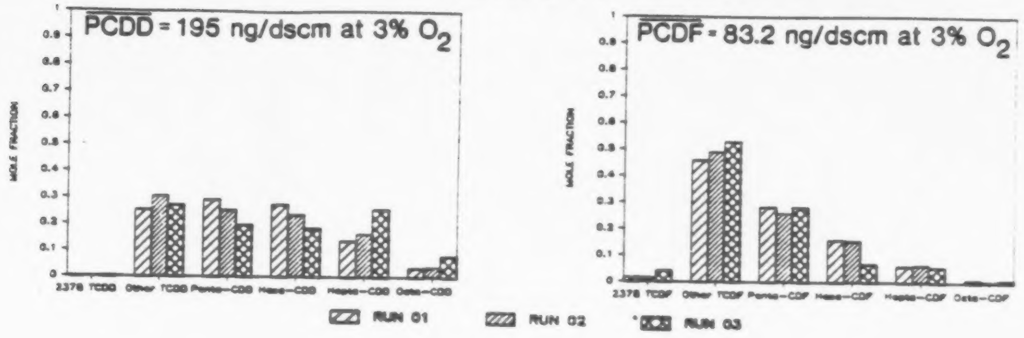
Figure 6 - 8.

WOOD COMBUSTION/OUTLET

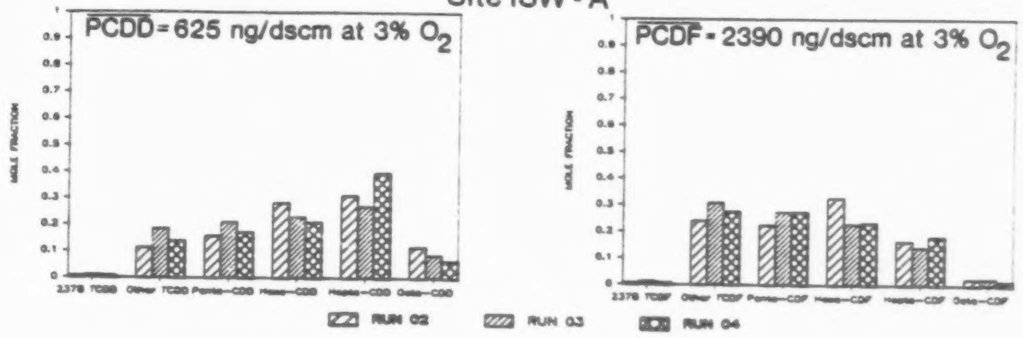
DIOXINS

FURANS

Site WFB - A



Site ISW - A



Site WS - A

Analytical Data were not Reported by Troika for MMS Samples taken at Site WS - A due to Unacceptable Surrogate Recovery Results

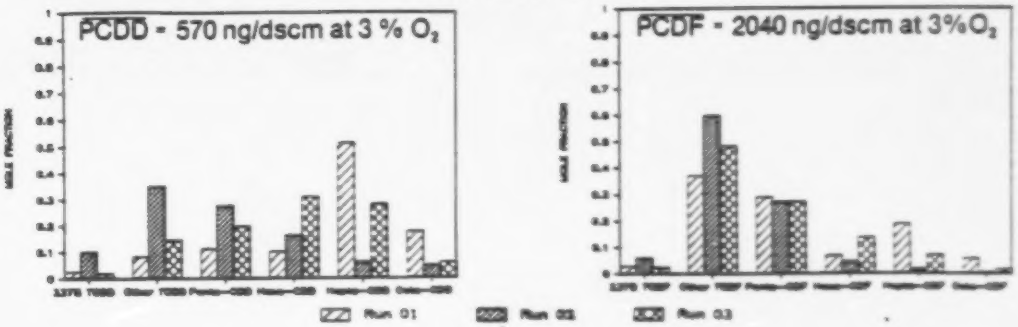
Dioxin/Furan Homologue Distributions of Controlled Emissions from Wood Combustion Processes (Sites WFB - A, ISW - A, WS - A)

Figure 6 - 9.

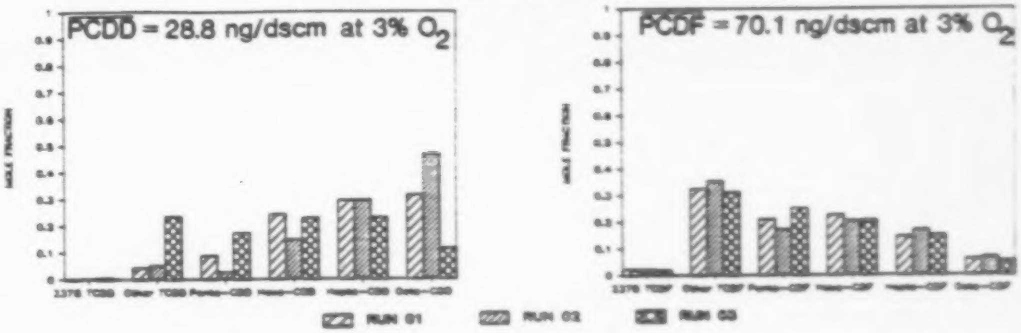
MISCELLANEOUS COMBUSTION SOURCES/INLET

DIOXINS **FURANS**

Site DBR - A



Site CRF - A



Dioxin/Furan Homologue Distributions of Uncontrolled Emissions from Miscellaneous Combustion Sources (Sites DBR - A, CRF - A)

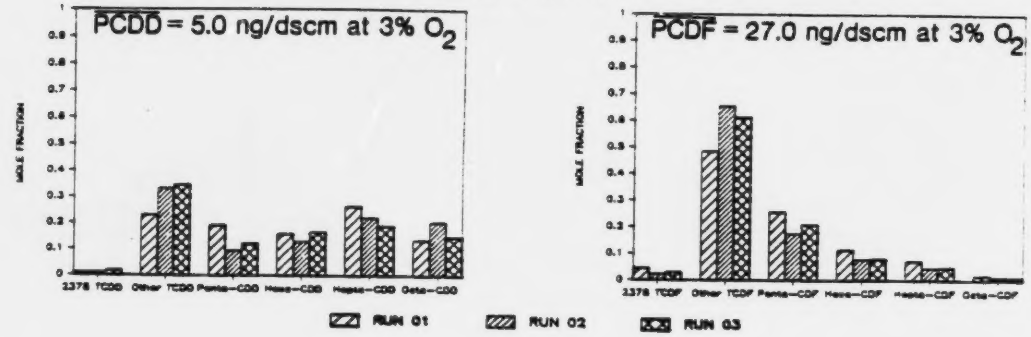
Figure 6 - 10.

MISCELLANEOUS COMBUSTION SOURCES/OUTLET

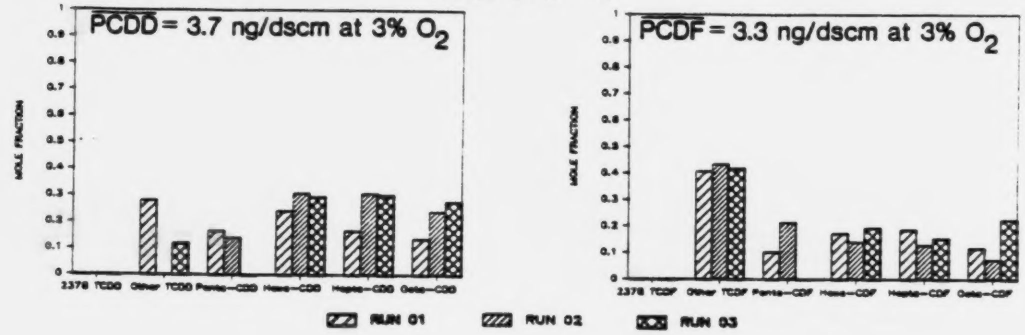
DIOXINS

FURANS

Site DBR - A



Site CRF - A



Dioxin/Furan Homologue Distributions of Controlled Emissions from Miscellaneous Combustion Sources (Sites DBR - A, CRF - A)

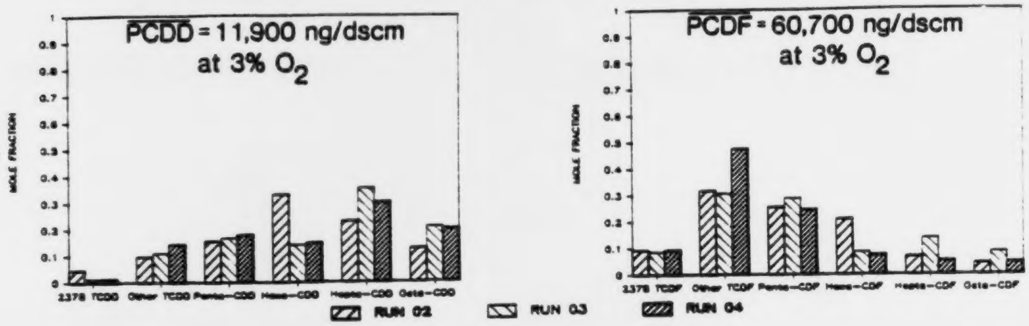
Figure 6 - 11.

METALS RECOVERY PROCESSES
OUTLET

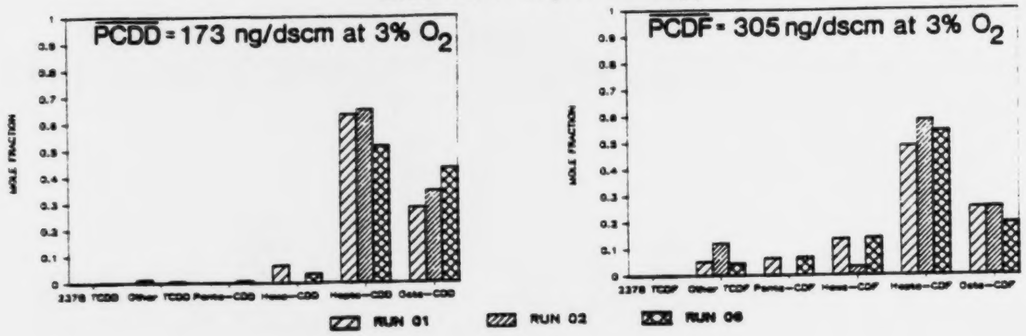
DIOXINS

FURANS

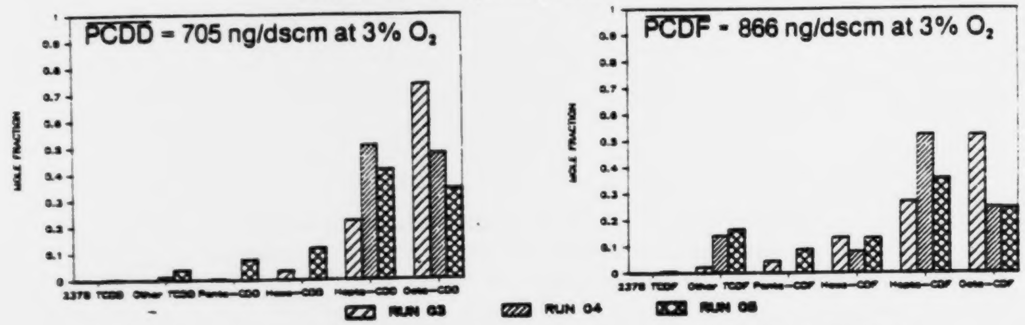
Site MET - A



Site WRI - A (Wire Only)



Site WRI- A (Wire and Transformers)



Dioxin/Furan Homologue Distributions of Controlled Emissions from Metals Recovery Processes
(Sites MET - A, WRI - A Wire Only, WRI - A Wire and Transformers)

Figure 6 - 12.

1. In general, reasonably good precision was found between test runs for a given site. This implies that each test site has a characteristic PCDD/PCDF "fingerprint." However, these fingerprints could not be readily tied to specific precursors in the feed materials.
2. A wide variation in PCDD/PCDF fingerprints was found between the Tier 4 test sites. This has important implications in health risk analysis since each homologue has a different unit risk factor.
3. The homologue distribution of PCDD's was not necessarily similar to that of PCDF's for a given site (e.g., high octa-CDD's did not imply high octa-CDF's for the black liquor boilers).
4. In general, the homologue distributions did not shift significantly across the control devices for which inlet/outlet data are available (e.g., compare the inlet homologue distribution for Sites SSI-C, BLB-A, BLB-B, BLB-C, WFB-A, DBR-A, and CRF-A to the outlet homologue distribution for these sites). This implies that there do not appear to be significant differences in the controllability of emissions of the various PCDD/PCDF homologues.
5. There appear to be some similarities in the homologue distributions for source categories that were tested more than once in the Tier 4 program (i.e., sewage sludge incinerators and black liquor boilers). However, there are also some notable differences from source categories. For example, the inlet homologue distribution for Site BLB-C (West Coast pulp mill) is noticeably different from that for Sites BLB-A and BLB-B (East Coast pulp mills). These differences may be attributable to variations in feed materials within source categories (e.g., different types of wood).

6.4 CONTROL DEVICE EFFICIENCY RESULTS

This section presents air pollution control device PCDD/PCDF removal efficiency results for the seven Tier 4 test sites for which sampling and analysis were performed upstream and downstream of a control device. There were no studies identified in the literature that reported control device efficiency data for PCDD and/or PCDF emissions. The control devices tested in the Tier 4 program include three electrostatic precipitators (Sites BLB-A, BLB-B, and BLB-C), one baghouse (Site WFB-A), one dry scrubber/baghouse combination (Site CRF-A), one water scrubber (Site SSI-C), and one afterburner (Site DBR-A).

Section 6.4.1 provides an overview of the removal efficiency data, and Section 6.4.2 considers uncertainties in the results. The specific control devices tested are discussed in Section 6.4.3. General conclusions and observations are presented in Section 6.4.4.

6.4.1 Overview of the Removal Efficiency Data

Run-specific removal efficiency data for 2378-TCDD, total PCDD, and total PCDF are shown in Tables 6-12 and 6-13 for the seven control devices tested in the Tier 4 program. In general, the data indicate a wide range of measured removal efficiencies for the seven devices tested. Average measured removal efficiencies for total PCDD's ranged from a low of -130 percent for the baghouse at Site WFB-A (i.e., an increase in total PCDD across the baghouse) to a high of +99 percent for the afterburner at Site DBR-A (i.e., a decrease in total PCDD across the afterburner). Average measured removal efficiencies for total PCDF's ranged from values less than zero for the water scrubber at Site SSI-C and the electrostatic precipitator at Site BLB-C to a high of +99 percent for the afterburner at Site DBR-A.

Between-run variations were large for all devices tested except the dry scrubber/baghouse combination at Site CRF-A and the afterburner at Site DBR-A. These two devices showed consistently high removal efficiencies for all test runs (i.e., 80 to 100 percent). Data for the individual PCDD and PCDF homologues varied considerably for specific test runs at all sites except CRF-A and DBR-A, which also showed consistently high removal efficiencies for all homologues. Much of the variability observed for the remaining five control devices is accounted for by the relatively large (i.e., ±50 percent) uncertainty in the CDD/CDF analytical data combined with the lower efficiencies of these devices. These considerations are addressed in the following section.

TABLE 6-12. EMISSION CONTROL EFFICIENCY RESULTS (INDIVIDUAL RUN DATA)

Control Device/Test Site/Run Number	Emission Control Device Removal Efficiency (%)		
	2378 TCDD	Total PCDD	Total PCDF
Electrostatic Precipitators			
BLB-A			
Run 1	ND/I,0	5.5	32.0
Run 2	ND/I,0	43.7	47.3
Run 3	ND/I,0	88.7	93.7
Average	--	46.0	57.7
BLB-B			
Run 1	ND/I,0	-103.8	-466.3
Run 2	ND/I,0	75.8	82.2
Run 3	ND/I,0	98.1	80.2
Average	--	(23.4)	(-101)
BLB-C			
Run 1	ND/I,0	89.4	97.5
Run 2	ND/I,0	44.3	74.3
Run 3	ND/I,0	52.6	-52.9
Average	--	62.1	(39.6)
Baghouse			
WFB-A			
Run 1	NR/I	-243.2	9.2
Run 2	70.9	-137.6	35.6
Run 3	56.3	-8.0	73.5
Average	63.6	-129.6	39.4
Spray Dryer/Baghouse			
CRF-A			
Run 1	100.0	82.0	93.1
Run 2	100.0	89.8	95.1
Run 3	100.0	91.7	96.9
Average	100.0	87.8	95.0

(Continued)

TABLE 6-12. EMISSION CONTROL EFFICIENCY RESULTS (INDIVIDUAL RUN DATA) (Continued)

Control Device/Test Site/ Run Number	Emission Control Device Removal Efficiency (%)		
	2378 TCDD	Total PCDD	Total PCDF
Water Scrubber			
SSI-C			
Run 1	NR/I	NR/I	NR/I
Run 2	NR/I	27.9	-21.6
Run 3	NR/I	51.4	27.9
Average	--	39.7	(3.1)
Afterburner			
DBR-A			
Run 1	99.6	99.1	98.2
Run 2	99.8	98.4	98.0
Run 3	99.5	99.6	99.4
Average	99.6	99.0	98.5

Note: Values in parenthesis ( ) indicate averages calculated from positive and negative values.
ND = species not detected.
NR = data not reported by Troika.
/I,O = applicable to inlet and outlet sampling locations.
/I = applicable to inlet sampling location.
/O = applicable to outlet sampling location.

TABLE 6-13. AVERAGE EMISSION CONTROL EFFICIENCIES AND INLET CONCENTRATIONS FOR TOTAL PCDD AND TOTAL PCDF

Control Device/ Test Site	Total PCDD Inlet Concentration (ng/dscm @ 3% O_2)	Total PCDD Average Measured Efficiency (Percent)	Total PCDF Inlet Concentration (ng/dscm @ 3% O_2)	Total PCDF Average Measured Efficiency (Percent)
Electrostatic Precipitators				
BLB-A	1.8	46	1.5	58
BLB-B	17.1	(23)	1.1	(-101)
BLB-C	9.0	62	15.1	40
Baghouse				
WFB-A	102	-130	154	39
Spray Dryer/Baghouse				
CRF-A	28.8	88	70.1	95
Water Scrubber				
SSI-C	101	40	507	(3.1)
Afterburner				
DBR-A	687	99	2,170	99

Note: Values in parentheses ( ) indicate averages calculated from positive and negative values.

6.4.2 Uncertainty Analysis

An uncertainty analysis for control device efficiency calculations is detailed in Appendix A.4. Assuming an uncertainty of ±50 percent for a given analytical result, the uncertainty analysis indicates the following conclusion:

> the minimum and maximum bounds (E_{min}, E_{max}) on the "true" efficiency corresponding to a given measured efficiency (E_{meas}) for an individual CDD/CDF homologue are expressed by the relationships:
>
> $$E_{max} = (200 + E_{meas})/3, \quad \text{and}$$
>
> $$E_{min} = 3E_{meas} - 200$$

In practical terms, these relationships suggest that measured control efficiencies greater than 67 percent represent definite positive control (i.e., $E_{min} > 0$), measured efficiencies between -200 percent and 67 percent represent potentially positive or negative control (i.e., $E_{max} > 0$ but $E_{min} < 0$), and measured efficiencies less than -200 percent represent definite negative control. With the exception of the dry scrubber/baghouse combination at Site CRF-A and the afterburner at Site DBR-A, the control devices tested in the Tier 4 program generally exhibited measured control efficiencies in the intermediate range (i.e., $-200 < E < 67$). This implies that these devices were only marginally effective or potentially not effective at all in reducing CDD/CDF emissions under the conditions tested. The consistently high measured control efficiencies for the dry scrubber/baghouse combination at Site CRF-A and the afterburner at Site DBR-A indicates that these control devices were very effective in reducing CDD/CDF emissions.

6.4.3 Evaluation of Specific Control Devices

In this section, each of the control device types tested is considered in more detail.

6.4.3.1 Electrostatic Precipitators (Sites BLB-A, BLB-B, and BLB-C). PCDD/PCDF control efficiencies for three electrostatic precipitators were measured in the Tier 4 program (Sites BLB-A, BLB-B, and BLB-C). All of the ESP's were used to control particulate emissions from black liquor boilers. As shown in Table 6-12, these ESP's operated at average outlet temperatures ranging from 146°C to 175°C (295°F to 350°F), and each was designed for high particulate removal efficiency (salt cake recovery). The units at Sites BLB-B and BLB-C are dry bottom ESP's, and the unit at Site BLB-A is a wet bottom ESP.

Viewed as a whole, the removal efficiency results in Table 6-12 and Table 6-13 suggest that a limited degree of control (i.e., 60 percent or less) was achieved across the ESP's for both PCDD's and PCDF's. Negative efficiency values were calculated for some homologues and for some test runs, but the measured efficiency values were in the range where analytical uncertainties could have caused these as artifacts of the data rather than indicating true results. Another problem confounding the evaluation of the ESP removal efficiency data is the relatively low PCDD/PCDF inlet concentrations associated with the black liquor boilers. In many cases, measured concentration values for specific homologues were at or near (i.e., within a factor of 3 or 4) the analytical detection limits.

6.4.3.2 Baghouse (Site WFB-A). PCDD control efficiencies were measured for one baghouse in the Tier 4 program (Site WFB-A). The baghouse was used to control particulate emissions from a boiler firing salt-laden wood. As shown in Table 5-14, the baghouse operated at an average temperature of approximately 224°C (435°F) during the test runs.

The removal efficiency results in Table 6-12 and Table 6-13 suggest that the baghouse exhibited negative control for PCDD's (i.e., increases in concentration across the baghouse) and positive control for PCDF's. The average measured total PCDD removal efficiency of the baghouse was -130 percent, and the average measured total PCDF removal efficiency was +39 percent. The measured control efficiency values for individual PCDD homologues were typically within the range explainable by low positive removal efficiency and the ±50 percent analytical uncertainty. However, the consistently negative values indicate little or no control as a likely explanation of the data. The measured control efficiency values for PCDF's indicate a limited positive degree of control. Inlet concentrations to the baghouse were large relative to the minimum detectable levels.

6.4.3.3 Spray Dryer/Baghouse Combination. PCDD/PCDF control efficiencies for one spray dryer/baghouse combination were measured in the Tier 4 program (Site CRF-A). The spray dryer/baghouse was used to control particulate and HCl emissions from a carbon regeneration furnace equipped with an afterburner. In the spray dryer, an alkali solution (sodium carbonate) was injected into the hot gas stream leaving the afterburner. The cooled gas stream was then passed through the baghouse, which operated at an outlet temperature of 177°C (350°F) during the test runs. Sampling and analysis were performed downstream of the afterburner at the inlet and outlet of the spray dryer/baghouse combination.

The removal efficiency results in Table 6-12 and Table 6-13 show that the spray dryer/baghouse combination was very effective in reducing PCDD/PDCF emissions leaving the carbon regeneration furnace afterburner. The average measured total PCDD removal efficiency of the spray dryer/baghouse was +87.8 percent, and the average measured total PCDF removal efficiency was +95.0 percent. There was little variation between test runs for either PCDD or PCDF removal efficiency. The measured efficiency values were high enough to safely conclude that the spray dryer/baghouse combination provided positive control of PCDD and PCDF emissions, even when potential analytical uncertainties are considered. Inlet PCDD and PCDF concentrations to the spray dryer/baghouse were large relative to the minimum detectable levels.

6.4.3.4 Water Scrubber. PCDD/PCDF control efficiencies were measured for one water scrubber in the Tier 4 program (Site SSI-C). The scrubber was used to control particulate and organic emissions from a multiple hearth incinerator burning sewage sludge. As shown in Table 5-12, the outlet gas temperature from the scrubber was approximately 22°C (72°F).

The removal efficiency results in Tables 6-12 and 6-13 suggest that the scrubber provided a limited degree of control for PCDD's but little or no control for PCDF's. The average measured total PCDD removal efficiency was +40 percent, and the average total PCDF removal efficiency was 3 percent. The measured control efficiency values were low enough that the true values were most likely obscured by analytical uncertainties. Inlet PCDD and PCDF concentrations to the scrubber were large relative to the minimum detection levels.

6.4.3.5 Afterburner. PCDD/PCDF control efficiencies for one natural gas-fired afterburner were measured in the Tier 4 program (Site DBR-A). The afterburner was used to control hydrocarbon emissions from a drum and barrel reclamation furnace. As shown in Table 5-14, the afterburner operated at an average outlet temperature of 827°C (1520°F) during the test runs.

The removal efficiency results in Tables 6-12 and 6-13 show that the afterburner was very effective in reducing PCDD/PCDF emissions from the drum and barrel reclamation furnace. The average measured total PCDD removal efficiency of the afterburner was +99.0 percent, and the average measured total PCDF removal efficiency was +98.5 percent. There was little variation between test runs for either PCDD or PCDF removal efficiency. The measured efficiency values were high enough to safely conclude that the afterburner provided positive control of PCDD and PCDF emissions, even when potential analytical uncertainties were considered. Inlet PCDD and PCDF concentrations to the afterburner were large relative to the minimum detectable levels.

6.4.4 Summary of Control Efficiency Observations

The PCDD/PCDF emissions control data discussed in the previous sections show a wide range of PCDD/PCDF removal efficiencies for the control devices tested. The findings of the control efficiency data can be summarized as follows:

- The afterburner at Site DBR-A exhibited good control of PCDD's (99.0 percent) and PCDF's (98.5 percent) when subjected to high inlet concentrations of these species (687 and 2,170 ng/dscm @ 3% O_2, respectively).
- The spray dryer/baghouse combination at Site CRF-A showed good control of PCDD's (88 percent) and PCDF's (95 percent) when subjected to intermediate concentrations of these species (29 and 70 ng/dscm @ 3% O_2, respectively).
- The electrostatic precipitators at Sites BLB-A, BLB-B, and BLB-C exhibited a limited degree (i.e., less than 60 percent) of control for both PCDD's and PCDF's although the data are not conclusive.

The inlet PCDD and PCDF concentrations to these devices were low (maximums of 17 and 15 ng/dscm @ 3% O_2 for PCDD and PCDF, respectively).

- The water scrubber at Site SSI-C exhibited a limited degree of control for PCDD's (approximately 40 percent) and little or no control for PCDF's (3 percent) when subjected to intermediate inlet concentrations of these species (101 and 507 ng/dscm @ 3% O_2, respectively).
- The baghouse at Site WFB-A exhibited negative control of total PCDD's (-130 percent) and a limited degree of control for total PCDF's when subjected to intermediate inlet concentrations of these species (102 and 154 ng/dscm @ 3% O_2, respectively).

Absolute comparisons of the removal efficiency data between source categories are not quantitatively valid because the control devices were subjected to varying inlet flue gas conditions (e.g., widely varying PCDD/PDCF, HCl and moisture concentrations). However, several general observations regarding control of PCDD and PCDF emissions can be made. These observations are discussed below.

Perhaps the most important conclusion to be drawn from the Tier 4 control efficiency data is that effective particulate emissions control does not necessarily imply effective PCDD/PCDF control. This is most clearly demonstrated by the baghouse at Site WFB-A, which actually showed an increase in PCDD concentration across the control device. The data suggest that PCDD/PCDF formation/destruction reactions can occur within the control device. Baghouses would seem ideally suited for this type of mechanism, since continuous flue gas/particulate matter contact is established at the bag surface. Reactive chlorine-containing species (e.g., HCl) present in the flue gas may interact with compounds present in the particulate matter to produce PCDD's and PCDF's. In contrast to the baghouse at Site WFB-A, the spray dryer/baghouse combination at Site CRF-A showed good control for both PCDD's and PCDF's. Two possible reasons for this difference are 1) the water and alkali solution injected in the spray dryer, and 2) the relative temperatures of the two baghouses. The first hypothesis is consistent with the control device reaction mechanism suggested above. The purpose of the alkali spray at Site CRF-A is to remove HCl from the flue gas (as NaCl) prior to particulate control by the baghouse. Thus, the reactive HCl species is not available to participate in potential flue gas/particulate matter reactions on the bag surface. Also, the gas cooling provided by the spray dryer [(204°C to 927°C (400°F to 1700°F))] may provide nucleation sites for vapor phase PCDD/PCDF condensation onto particulate matter surfaces, which would also be expected to improve PCDD/PCDF removal efficiency across the spray dryer/baghouse combination.

The relative temperature of the baghouses at Sites CRF-A [(177°C (350°F))] and WFB-A [(224°C (435°F))] may also play a role in the relative PCDD/PCDF control effectiveness of these two devices. However, a temperature differential of this magnitude would not be expected to cause such a large difference in control efficiency. The data developed for the water scrubber at Site SSI-C indicate that gas cooling alone does not necessarily imply effective PCDD/PDCF control. The outlet temperature of the water scrubber [(22°C (72°F))] was the lowest of all the control devices tested, yet the water scrubber did not provide good PCDD/PCDF control. The operating temperature/removal efficiency data for the three electrostatic precipitators tested seem to fit the trend of decreasing PCDD/PCDF control efficiency with increasing temperature. However, the validity of this trend may be obscured by the variability in the measured efficiency data for these sites.

Another important observation that can be made from the Tier 4 control efficiency data is that properly operated afterburners can be very effective PCDD/PCDF control devices. This is clearly demonstrated by the data from Site DBR-A, which exhibited average afterburner removal efficiencies of 99.0 and 98.5 percent for PCDD's and PCDF's, respectively.

Homologue distribution shifts across the control devices tested were not found to be significant. This is illustrated by qualitative comparisons of the inlet/outlet homologue distribution pairs in Section 6.3. Also, large differences were not found between control efficiencies for PCDD's and PCDF's. The exception to this rule was the baghouse at Site WFB-A, which showed poorer control for PCDD's than for PCDF's.

CHAPTER 7

QUALITY ASSURANCE PROGRAM

This section discusses the Quality Assurance and Quality Control (QA/QC) program implemented for the Tier 4 study. The objectives of the QA program and a summary of the QC activities are discussed. An assessment of data quality for key measurement parameters is also provided. Quality assurance support to the Tier 4 program was provided by Research Triangle Institute (RTI). Results of their quality assurance effort are presented in the document entitled "National Dioxin Study Tier 4: Combustion Sources." Quality Assurance Evaluation. EPA 450/4-84-014f.

Throughout this chapter, the Tier 4 test sites are designated by numbers (01 through 13), corresponding to the chronological sequence in which the tests were performed. This was done so that changes occurring during the course of the program (e.g., sampling protocol, data quality, etc.) could be easily tracked for the various test sites. A table matching the site codes and the test numbers for the various test sites is provided in Table 7-1.

7.1 QA PROGRAM OBJECTIVES

For any measurement effort, there always exists some degree of uncertainty associated with the measured data due to inherent limitations of the measurement system. The utility of the measured data is largely dependent on the degree to which the magnitude of this uncertainty is known. The Tier 4 testing program incorporated a comprehensive QA/QC plan. The overall objective of this plan was to produce complete, representative, and comparable data of known quality.

The Tier 4 QA/QC program emphasized 1) adherence to prescribed sampling procedures, 2) careful documentation of sample collection and field

TABLE 7-1. TEST SITE NUMBERS AND COMBUSTION DEVICE CODES

Site Number	Site Code
01	SSI-A
02	ISW-A
03	SSI-B
04	BLB-A
05	BLB-B
06	WRI-A
07	WFB-A
08	BLB-C
09	CRF-A
10	MET-A
11	DBR-A
12	SSI-C
13	WS-A

analytical data, 3) use of chain-of-custody records, 4) adherence to prescribed analytical procedures, and 5) implementation of independent systems and performance audits. In combination, these QA/QC efforts served two purposes. First, the QA/QC efforts provided the mechanism for controlling data quality to within acceptable limits. Second, they formed the basis for estimates of uncertainty by providing the necessary information for defining error limits associated with the measured data.

The QA objectives for each key parameter measured during the Tier 4 test program are shown in Table 7-2. These objectives were based largely on the accuracy and precision typically achieved for the methods selected. For all GC/MS analyses (MM5 CDD/CDF; chlorobenzenes, chlorophenols, and polychlorinated biphenyls) standard extraction and analysis procedures were initially used. Difficulties were encountered for certain feed materials and MM5 samples containing high levels of contamination. Therefore, even though extraction/cleanup procedures were modified to improve spiked surrogate recoveries, QA objectives were still not met for some samples. Despite the fact that QA objectives were not achieved for these samples, the analytical results obtained are still considered adequate to address the objectives of Tier 4. Site WS-A (13) is the only site for which CDD/CDF emissions data were invalidated due to QA concerns. Surrogate recoveries for the MM5 samples were well below the QA objectives for this site.

The QA/QC activities for the Tier 4 program are summarized in Section 7.2 and data quality assessments are provided in Section 7.3.

7.2 SUMMARY OF QA/QC ACTIVITIES

This section provides a summary of QA/QC activities and results for three main areas: field sampling, field and laboratory analysis, and independent audits. Additional detail on the activities associated with the

TABLE 7-2. SUMMARY OF TIER 4 DATA QUALITY OBJECTIVES

Parameter	Method	Precision	Accuracy
Flue Gas Dioxin/Furan	Modified Method 5 and GC/MS	50%[a]	±50%[a]
HCl Concentration	HCl Acid Train	10%[b]	±7%[c]
Velocity/Volumetric Flowrate	EPA Method 1 and 2	6%[d]	±10%[d]
Moisture Gases/Molecular Weight	Modified EPA Method 3	10%[e]	±20%[c]
Moisture	EPA Method 4	20%[d]	±10%[d]
Flue Gas O_2	Paramagnetic Analyzer	20%[d]	±10%[d]
Flue Gas CO	Nondispersive Infrared Analyzer	20%[e]	±10%[c]
Flue Gas CO_2	Nondispersive Infrared Analyzer	20%[e]	±20%[c]
Flue Gas SO_2	Pulsed Fluorescent Analyzer	20%[e]	±20%[c]
Flue Gas THC	Flame Ionization Analyzer	20%[e]	±20%[c]
Chlorobenzenes	Gas Chromatograph/Mass Spectrometer (GC/MS)	50%[b]	±50%[f]
Chlorophenols	GC/MS	50%[b]	±50%[f]
Polychlorinated Biphenyls	GC/MS	50%[b]	±50%[f]
Total Chlorine	GC/MS	6%[b]	±30%[f]

[a] Based on Troika analytical precision and accuracy objectives for duplicate and quality control samples (see Section 7.2.2).

[b] Percent difference from duplicate analyses, where $\% = \frac{\text{First Value} - \text{Second Value}}{0.5\ (\text{First} + \text{Second Values})} \times 100\%$

[c] Relative error (%) for audit analyses, where $\% = \frac{\text{Measured Value} - \text{Actual Value}}{\text{Actual Value}} \times 100\%$

[d] Precision and accuracy estimated based on results of EPA collaborative tests.

[e] Coefficient of variation (CV) for daily analyses of control sample, where $CV = \frac{\text{Standard Deviation}}{\text{Mean}} \times 100\%$

[f] Relative error (%) for GC/MS analysis based on spiked internal standards, where $\% = \frac{\text{Measured Value} - \text{Spiked Value}}{\text{Spiked Value}} \times 100\%$

sampling and analytical efforts is provided in the Tier 4 Quality Assurance Project Plan (QAPP)[A] and the Dioxin Analytical Procedures and Quality Assurance Plan for Tier 4.[B]

7.2.1 Sampling Activities

Quality control for flue gas and process sampling centered around 1) equipment calibration, 2) glassware and sampling equipment cleaning, 3) procedural QC checks, and 4) sample custody procedures. Key activities and QC results in each of these areas are discussed below.

Pre-test calibrations or inspections were conducted on pitot tubes, sampling nozzles, temperature sensors and analytical balances. Both pre- and post-test calibrations were also performed on the dry gas meters used for MM5, HCl, and ambient train sampling. All of this equipment met the calibration criteria specified in the Tier 4 QAPP. Differences between pre- and post-test dry gas meter calibrations for each of the 13 tests were less than 4.3 percent.

An extensive pre-cleaning procedure was implemented for all sample train glassware, sample containers and sampling tools. This cleaning procedure, which is outlined in Table 7-3, was implemented to minimize the potential for sample contamination with substances that may have interfered with the analysis for CDD's and CDF's. All sample train glassware was capped with foil prior to use and stored in a dust-free environment. A clean sample trailer was maintained for train assembly and sample recovery. To document the effectiveness of the glassware pre-cleaning procedure, a sample train "proof blank" was obtained for each site beginning with Site 04

[A] National Dioxin Study--Tier 4 Combustion Sources. Quality Assurance Project Plan. EPA-450/4-84-014e.

[B] Analytical Procedures and Quality Assurance Plan for the Analysis of Tetra Through Octa Chlorinated Dibenzo-p-Dioxins and Dibenzofurans in Samples from Tier 4 Incineration Processes. Addendum to: "Analytical Procedures and Quality Assurance Plan for the Analysis of 2378-TCDD in Tier 3-7 Samples of the U. S. Environmental Protection Agency National Dioxin Strategy." EPA/600/3-85/019, April 1985.

TABLE 7-3. TIER 4 GLASSWARE PRECLEANING PROCEDURE

1. Soak all glassware in hot soapy water (Alconox^R) 50°C or higher.
2. Distilled/deionized H_2O rinse (X3).[a]
3. Distilled/deionized H_2O rinse (X3).
4. Chromerge^R rinse if glass, otherwise skip to 6.
5. High purity liquid chromatography grade H_2O rinse (X3).
6. Acetone rinse (X3), (pesticide grade).
7. Methylene chloride[b] rinse (X3), (pesticide grade).
8. Oven dry (110°C - 2 hrs).
9. Cap glassware with clean glass plugs or $MeCl_2$-rinsed aluminum foil.

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[a] (X3) = three times.

[b] For Sites 01 through 04 hexane was used as the solvent for this last rinse.

(BLB-A). The proof blank was obtained from a complete set of MM5 sample train glassware that had been cleaned by the procedure in Table 7-3. The pre-cleaned glassware was rinsed with the sample recovery solvents (acetone and methylene chloride) and the rinses were analyzed for CDD/CDF. Results of the proof blank analyses are presented in Table 7-4.

Procedural QC activities during manual gas sampling for CDD/CDF and HCl focused on:

- visual equipment inspections,
- use of sample train blanks,
- ensuring the proper location and number of traverse points,
- conducting pre-test and post-test sample train leak checks,
- maintaining proper temperatures at the filter housing, sorbent trap, and impinger train,
- maintaining isokinetic sampling rates, and
- recording all data on preformatted field data sheets.

Results of isokinetic calculations and leak checks for MM5 and HCl sampling at the Tier 4 sites are presented in Table 7-5. The QA objectives for each test run were a leak free sample train and an average isokinetic sampling rate of 100 ±10 percent.

As shown in Table 7-5, the isokinetics objective was exceeded for at least one MM5 test run at Sites 01, 02, 06, 08 and 12 and for at least one HCl test run at Sites 02, 04, 05, 06 and 07. Of the 64 MM5 test runs, nine test runs or 14 percent exceeded the isokinetics QA objective. For the HCl train, 13 of the 33 test runs were outside the target 100 ±10 percent isokinetic sampling rate. In most cases, problems in achieving the isokinetics QA objective were caused by the normal but wide fluctuations in stack gas flowrates and moisture contents typical of batch processes. This was particularly true for the batch type combustion processes tested at Sites 02 (ISW-A) and 06 (WRI-A). In other cases the isokinetics objective was exceeded because of unexpected changes in the flue gas moisture content between test runs.

Sampling outside the isokinetics objective potentially affects the total mass and size distribution of particulate matter collected on the

TABLE 7-4. ANALYSIS RESULTS FOR TIER 4 MODIFIED METHOD 5 PROOF BLANKS

Compound	Site 04	Site 05	Site 06	Site 07	Site 08	Site 09	Site 10	Site 11	Site 12	Site 13
	Surrogate Recoveries, Percent									
$^{37}Cl_4$-TCDD[a]	84	NS	NA	NA	NA	82	82	NA	NS	NA
$^{13}C_{12}$-TCDD[a]	86	98	NA	NA	NA	80	82	NA	110	NA
$^{37}Cl_4$-Hepta-CDD[b]	47	NS	NA	NA	NA	116	108	NA	76	NA
$^{13}C_{12}$-Octa-CDD[b]	79	75	NA	NA	NA	79	93	NA	71	NA
	Amount Detected per Train, Nanograms									
2,3,7,8-TCDD	ND	ND	NA	NA	NA	NA	NA	NA	ND	NA
Other TCDD	ND	ND	NA	NA	NA	ND	0.2	NA	0.2	NA
Penta-CDD	ND	ND	NA	NA	NA	ND	ND	NA	ND	NA
Hexa-CDD	ND	ND	NA	NA	NA	ND	ND	NA	ND	NA
Hepta-CDD	ND	ND	NA	NA	NA	0.7	ND	NA	ND	NA
Octa-CDD	0.5	ND	NA	NA	NA	0.8	1.3	NA	0.4	NA
2,3,7,8-TCDF	ND	ND	NA	NA	NA	NA	NA	NA	ND	NA
Other TCDF	ND	ND	NA	NA	NA	0.9	1.6	NA	0.4	NA
Penta-CDF	ND	ND	NA	NA	NA	0.7	ND	NA	0.1	NA
Hexa-CDF	ND	ND	NA	NA	NA	1.9	0.3	NA	0.3	NA
Hepta-CDF	ND	ND	NA	NA	NA	2.6	0.5	NA	0.3	NA
Octa-CDF	ND	ND	NA	NA	NA	1.1	0.4	NA	0.4	NA

[a] Spiked at 5 ng in each sample.
[b] Spiked at 20 ng in each sample.
NS = Compound was not spiked into this sample.
ND = Not Detected. Minimum limits of detection ranged from 0.01 to 0.4 nanograms per sample train.
NA = Compound was not analyzed for in this sample.

TABLE 7-5. SUMMARY OF ISOKINETIC CALCULATIONS AND LEAK CHECK RESULTS FOR MM5 AND HCl

TEST SITE	TEST RUN	CONTROL DEVICE	OUTLET ISOKINETICS	MEETS QC OBJECTIVE	INLET ISOKINETICS	MEETS QC OBJECTIVE	HCL ISOKINETICS	MEETS QC OBJECTIVE	LEAK CHECK
1/SSI-A	9	SCRUBBER	95.6	YES	96.8	YES	N/S[a]	N/A[b]	GOOD
	10		94.7	YES	99.9	YES	N/S	N/A	GOOD
	11		103.4	YES	111.8	NO[c]	N/S	N/A	GOOD
2/ISW-A	1	AFTERBURNER	104.0	YES	N/S	N/A	102.3	YES	GOOD
	2		103.9	YES	N/S	N/A	101.3	YES	HCL TRAIN LEAK[d]
	3		112.0	NO	N/S	N/A	111.8	NO	HCL TRAIN LEAK
	4		111.4	NO	N/S	N/A	118.3	NO	GOOD
3/SSI-B	1	SCRUBBER	109.3	YES	N/S	N/A	N/S	N/A	GOOD
	3		106.1	YES	N/S	N/A	N/S	N/A	GOOD
	5		107.6	YES	N/S	N/A	N/S	N/A	GOOD
4/BLB-A	1	ESP	91.7	YES	92.5	YES	97.1	YES	GOOD
	2		106.5	YES	98.7	YES	108.6	YES	GOOD
	3		108.8	YES	104.7	YES	110.9	NO	GOOD
	4		N/S	N/A	N/S	N/A	115.4	NO	GOOD
5/BLB-B	1	ESP	98.0	YES	103.9	YES	109.9	YES	GOOD
	2		104.8	YES	102.8	YES	112.9	NO	GOOD
	3		103.7	YES	102.6	YES	113.8	NO	GOOD
6/WRI-A	1	AFTERBURNER	120.5	NO	N/A	N/A	136.7	NO	GOOD
	2		111.3	NO	N/A	N/A	129.3	NO	GOOD
	3		110.1	NO	N/A	N/A	113.2	NO	GOOD
	4		111.1	NO	N/A	N/A	127.9	NO	GOOD
	5		100.2	YES	N/A	N/A	115.2	NO	GOOD
	6		103.5	YES	N/A	N/A	107.7	YES	GOOD
	7		N/A	N/A	N/A	N/A	113.0	NO	GOOD
7/WFB-A	1	BAGHOUSE	99.7	YES	104.8	YES	106.4	YES	GOOD
	2		105.1	YES	107.2	YES	111.5	NO	GOOD
	3		101.7	YES	106.3	YES	104.6	YES	GOOD
8/BLB-C	1	ESP	105.4	YES	109.6	YES	105.9	YES	GOOD
	2		105.5	YES	114.1	NO	101.6	YES	GOOD
	3		109.2	YES	105.7	YES	102.3	YES	GOOD
9/CRF-A	1	BAGHOUSE	109.9	YES	105.3	YES	95.0	YES	GOOD
	2		102.0	YES	104.3	YES	93.4	YES	GOOD
	3		100.4	YES	97.9	YES	94.9	YES	GOOD
10/MET-A	1	BAGHOUSE	107.1	YES	N/S	N/A	97.5	YES	GOOD
	2		102.2	YES	N/S	N/A	104.8	YES	GOOD
	3		105.7	YES	N/S	N/A	103.2	YES	GOOD

TABLE 7-5. CONTINUED

TEST SITE	TEST RUN	CONTROL DEVICE	OUTLET ISOKINETICS	MEETS QC OBJECTIVE	INLET ISOKINETICS	MEETS QC OBJECTIVE	HCL ISOKINETICS	MEETS QC OBJECTIVE	LEAK CHECK
11/DBR-A	1	AFTERBURNER	101.8	YES	98.8	YES	109.4	YES	GOOD
	2		96.8	YES	90.7	YES	108.4	YES	GOOD
	3		101.3	YES	98.5	YES	102.8	YES	GOOD
12/SSI-C	1	SCRUBBER	99.3	YES	95.1	YES	N/S	N/A	MM5 TRAIN LEAK[d]
	2		86.2	NO	90.7	YES	N/S	N/A	GOOD
	3		97.1	YES	106.7	YES	N/S	N/A	GOOD
13/WS-A	1	NONE	[e]	N/A	[e]	N/A	[e]	N/A	GOOD
	2		[e]	N/A	[e]	N/A	[e]	N/A	GOOD
	3		[e]	N/A	[e]	N/A	[e]	N/A	GOOD

[a] NS = not sampled

[b] N/A = not applicable

[c] "No" implies that QC objective of 100 + 10 percent for isokinetics was not met. See text for explanation.

[d] See text for explanation of leak check problems,

[e] No attempt was made during the Site 13 (woodstove) test to sample isokinetic conditions because of the extremely low and variable gas flow rate.

filter. However, the measured exceedances in the isokinetics QA objective were generally small (i.e., an additional ±10 percent above the QA objective of 100 ±10 percent), and are not expected to have had a significant effect on measured concentrations of CDD/CDF or HCl. Estimates for chlorine emitted with particulate matter based on the HCl sampling trains may be somewhat in error for cases where the isokinetics QA objective was not achieved. However, no test data were invalidated on the basis of poor isokinetic sampling rates.

Initial, final, and port change leak checks for the MM5 and HCl sample trains were performed for each test run. The only leaks detected were at Sites 02 and 12. At Site 02, the glass probes on the HCl trains were found to be broken at the end of test Runs 2 and 3. The actual time that the breakage occurred during sampling is not known, but the breakage is most likely to have occurred either during the port change or when the train was removed from the stack for disassembly. Following a review of the chloride analysis results, the HCl data for Run 2 were invalidated because the HCl values determined for this run were unreasonably low compared with Runs 1 and 4. Results for Run 3 were very similar to those for Runs 1 and 4 and it appears that this probe was not broken until the sampling was completed.

At Site 12, Run 1, a leak in the MM5 sampling train was detected during testing at the scrubber inlet. During this sampling period, six ports were traversed at the scrubber inlet. A leak check performed after the first four ports showed no indication of leakage. However, a leak check performed after traversing the last two ports revealed that the filter holder was broken. It is not known if the breakage occurred before, during or after testing of the last two ports. Rather than discard the entire test run, a decision was made to use the results to provide a range of CDD/CDF concentrations entering the scrubber. The higher concentration will be based on the sample volume at the end of the fourth port and the lower concentration will be based on the volume at the end of the sixth and final port. All other test runs at Site 12 showed no indication of leakage.

Sample custody procedures used during this program emphasized careful documentation of the samples collected and the use of chain-of-custody records for samples transported to the laboratory for analysis. Steps taken to identify and document samples collected included labeling each sample with a unique alphanumeric code and logging the sample in a master logbook. All samples shipped to Troika or returned to Radian-RTP were also logged on chain-of-custody records that were signed by the field sample custodian upon shipment and also signed upon receipt at the laboratory. Each sample container lid was individually sealed to ensure that samples were not tampered with.

7.2.2 Analytical Activities

Laboratory and field analyses were conducted during the Tier 4 study to determine 1) the CDD/CDF contents of flue gas and process samples, 2) the CDD precursor contents of combustion device feed samples, 3) the HCl concentrations of the impinger catch from HCl sampling trains, and 4) the concentrations of CO, CO_2, O_2, SO_2, NO_x and total hydrocarbons (THC) in the flue gas.

Quality control (QC) activities for each of these analyses are described in detail in the Tier 4 QAPP and the Dioxin Analytical Procedures and QA Plan. Activities for all of these analyses included daily instrument calibration with certified standards to establish calibration or response factors and to verify proper instrument operation. Other QC activities specific to CDD/CDF analyses, CDD precursor analyses, and continuous monitoring of flue gas parameters are summarized in this section. Results of QC checks are discussed in Section 7.3.

CDD/CDF samples were extracted and analyzed by EPA's Troika laboratories in sets of twelve. Internal QC activities for the CDD/CDF analyses are summarized in Table 7-6. These activities include the use of labeled surrogates, sample blanks, control samples and duplicate extractions and analyses. Specific criteria for defining minimum detectable limits and for confirming positive identification of 2378-TCDD, other CDD's, and CDF's were also employed as part of the QA/QC effort.

Quality control activities for samples analyzed for CDD precursors (i.e., chlorobenzenes, chlorophenols, chlorinated biphenyls, and total chlorine) were similar to those for the CDD/CDF analyses. With the

TABLE 7-6. SUMMARY OF CDD/CDF ANALYSIS QUALITY CONTROL CHECKS

Parameter[a]	Quality Control Check	Frequency of Analysis[a]	Acceptance Criteria
2378 TCDD	Labeled surrogate spike	Each sample.	50 to 120 percent recovery.
Other CDD's and CDF's	Labeled surrogate spike	Each sample	40 to 120 percent recovery.
All CDD's and CDF's	Method blank	Once every other extraction set, alternate with matrix blank.	Free of contamination at minimum detectable limit.
	Matrix blank	Once every other extraction set, alternate with control blank.	Free of contamination at minimum detectable limit.
	Fortified matrix blank	Once every other extraction set, alternate with control sample.	±50 percent of theoretical value.
	Control sample	Once every other extraction set, alternate with fortified matrix blank.	±50 percent of theoretical value.
	Duplicate sample (lab)	Once every other extraction set, alternate with composite duplicate (field).	Percent difference within 50 percent.
	Composite duplicate (field)	Once every other extraction set, alternate with duplicate sample (lab).	Percent difference within 50 percent.

[a] Samples were extracted in sets of 12.

exception of total chlorine, QC activities for CDD precursors included surrogate spikes, blanks, matrix spikes, and duplicates. Sample blanks and duplicate analyses were used as QC checks for total chlorine.

Quality control checks for the continuous monitoring of CO, CO_2, O_2, SO_2, NO_x and THC included calibration drift checks and daily analysis of a control standard. The control standard was a different standard than that used for instrument calibration.

7.2.3 Audit Activities

The audit activities for the Tier 4 program consisted of independent systems and performance audits of both the field and laboratory efforts. Radian performed systems and performance audits on field activities at Site 03 (SSI-B) and on laboratory activities for CDD precursors. Research Triangle Institute (RTI) conducted systems audits on field activities at Sites 02 (ISW-A), 05 (BLB-B), and 10 (MET-A).[c] RTI also performed a systems audit on the CDD precursor laboratory activities and provided audit samples for CDD/CDF analysis and total chloride analysis.

Objectives of the systems and performance audits were to 1) evaluate adherence to the test plans and QAPP, 2) document test and analytical procedures used, 3) provide information to allow assessment of data quality, and 4) make recommendations that could improve data quality. The results of field audits are presented in detail in the individual test reports for Sites 02 (ISW-A), 03 (SSI-B), 05 (BLB-B), and 10 (MET-A). A summary of audit activities and systems audit results is presented in this section. Performance audit results, with the exception of example MM5 calculations and dry gas meter audits, are discussed in Section 7.3.

Field systems and performance audits centered around manual sampling methods (e.g., MM5, HCl, and grab sampling), continuous flue gas monitoring, data documentation, and sample custody and handling. The systems audits showed that all field activities were being performed with strict adherence to the test plans and QAPP. Following each audit, recommendations were made for further improving data quality but no problems serious enough to invalidate test results were identified.

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[c] National Dioxin Study--Tier 4 Combustion Sources. Quality Assurance Evaluation. EPA-450/4-84-014f. January 1986.

Two modifications from the ASME MM5 protocol were noted by the RTI auditors. Both modifications had been previously approved by EPA. The first modification relates to the orientation of the condenser coil in the MM5 train. The ASME protocol specifies that both the condenser coil and the resin trap be oriented vertically. Radian has found, however, that substitution of a horizontal condenser (but not trap) works equally well without causing significant holdup of condensate in the coil or channeling of the condensate through the resin. The horizontal coil has an added advantage of reducing the space required for traversing the sampling train. A horizontal condenser coil was used throughout the Tier 4 test program.

The second modification implemented for Tier 4 relates to the solvents used for glassware cleaning and for rinsing the nozzle, probe, filter holder and cyclone (if used). The types of solvents used were changed several times during the period that the first five CDD source tests were conducted. For Site 01 (SSI-A) recovery of the glassware involved rinsing with deionized (DI) water, acetone, and then hexane. This procedure was changed for Sites 02 (ISW-A) and 03 (SSI-B) to eliminate the water rinse due to a revision of the ASME protocol (April 16, 1984 versus October, 1984 version). Water was reinstituted as the first of three solvents for Sites 04 (BLB-A), 05 (BLB-B), and 08 (BLB-C), all of which were black liquor boilers. The use of water for these particular sources was necessary to ensure recovery of acetone insoluble particulate from the glassware.

The last change in the glassware rinsing scheme was the substitution of methylene chloride for hexane to improve recovery of CDD present in the sample. This change was implemented for all test sites beginning with Site 05 (BLB-B). As will be discussed further in Section 7.3.1, relatively high quantities of octa-CDD's and CDF's were found in the field blank sample train for Site 01 and the substitution of methylene chloride for hexane was intended to improve recovery of these compounds.

During two of the audits, an example MM5 data sheet was provided to the test team to evaluate the computer program used for data reduction. In both cases the necessary calculations were accurately performed.

Dry gas meters used for MM5, HCl, and ambient sampling were also audited at three test sites. A calibrated orifice was used at Sites 02 (ISW-A) and 05 (BLB-B) to check three dry gas meters used in the Tier 4 study. All three dry gas meters agreed with the orifice flow rate to within ±2.0 percent. The dry gas meter used at Site 03 (SSI-B) was audited by direct comparison to a transfer dry gas meter which had been referenced to an independent wet test meter. A flow rate of approximately 0.4 cfm was used as a reference. The two dry gas meters agreed within ±2.7 percent, based on three 15-minute runs exhibiting a coefficient of variation of less than 1.3 percent.

Laboratory systems audits for the CDD precursor analyses were also conducted by Radian and RTI. In general, the results of these audits showed that the quality of the precursor analysis efforts was sufficient to meet Tier 4 objectives. However, a number of recommendations were made relating to sample handling, documentation of extraction procedures, and data reduction and review.

7.3 DATA QUALITY ASSESSMENTS

This section provides an estimate of the uncertainty in measurements made for 1) flue gas CDD/CDF concentrations, 2) ash CDD/CDF concentrations, 3) feed material precursor contents, and 4) flue gas combustion parameters. The uncertainty assessments are based on performance audit results and QC data.

7.3.1 Flue Gas CDD/CDF Analyses

Data available to assess the quality of flue gas CDD/CDF concentrations include audit results, fortified QC sample analyses, lab blanks, field blanks and sample surrogate recoveries. Based on the QA/QC data presented in this section, the accuracy achieved for the CDD/CDF analyses should be within ±50 percent, except for certain samples as noted.

CDD/CDF audit sample results are summarized in Table 7-7. Four samples containing 2378-TCDD were provided to Troika for analysis. As shown in Table 7-7, the difference between expected and measured values for detectable quantities of 2378-TCDD ranged from 0.3 to 40 percent.

Fortified QC sample results are presented in Table 7-8. The acceptance criterion for these samples was a measured value within ±50 percent of the amount spiked on the sample. As shown in Table 7-8, this criterion was met for all species in each QC sample with the exception of 2378-TCDF in QC samples for Sites 09 and 10. The high values of TCDF for Sites 09 and 10 are probably due to instrument background caused by large amount of TCDF in the Site 10 source samples. In reviewing CDD/CDF analytical results for Site 09, it should be recognized that reported values for TCDF may be somewhat higher than the actual values.

Analysis results for laboratory and field blanks are presented in Table 7-9 and Table 7-10, respectively. Spiked surrogate recoveries for the labeled TCDD's were within the target range of 40 to 120 percent. Surrogate recoveries for the labeled hepta- and octa-CDD's were also acceptable for all but one field blank. The recovery for hepta-CDD in the Site 09 inlet field blank (138 percent) was somewhat above the target range of 40 to 120 percent. This is not expected to have any significant effect on other samples from Site 09.

As shown in Table 7-9, the laboratory blanks were found to be clean with the exception of some OCDD and OCDF. The amount of OCDD or OCDF found in the blanks was generally at or near the minimum limit of detection. As shown in Table 7-10, the field blanks were also found to be clean with the exception of Sites 01, 02, 08, 10 and 11. For Sites 01, 02, 10 and 11, field blank values of up to 40 ng were detected for various isomers. However, for each of these sites, the field blank values were small relative to the MM5 test run values and no major problems related to sample recovery or contamination are suggested for samples from these sites.

For Site 08, hepta- and octa-CDD's and CDF's in the 3.5 to 109 ng range were found in the outlet field blank. These values are higher than those found in the MM5 test run samples from the control device inlet and outlet

TABLE 7-7. SUMMARY OF ANALYTICAL AUDIT RESULTS FOR 2378-TCDD

Sample Description	Expected Value	Measured Value	Percent Difference
2378-TCDD in NBS Urban Particulate	0.05 ppb	0.07 ppb	40
2378-TCDD in NBS Urban Particulate	0.007 ppb	ND[a]	--
NBS 2378-TCDD in Octane	67.8 ng/mL	68 ng/mL	0.3
NBS 2378-TCDD in Octane	67.8 ng/mL	69 ng/mL	1.8

[a] Reported method detection limit was 0.04 ppb.

TABLE 7-8. ANALYSIS RESULTS FOR FORTIFIED FLUE GAS QUALITY CONTROL SAMPLES

Compound	Spiked Quantity[a] (ng)	Site 01	Site 02	Site 03	Site 04	Site 05	Site 06	Site 07	Site 08	Site 09	Site 10	Site 11	Site 12
		Surrogate Recoveries, Percent											
$^{37}Cl_4$-TCDD	5	86	102	92	100	88	84	98	100	50	94	96	NS
$^{13}C_{12}$-TCDD	5	86	108	92	92	100	88	110	102	60	84	102	98
$^{37}Cl_4$-Hepta-CDD	20	86	64	63	57	70	45	42	62	70	80	41	41
$^{13}C_{12}$-Octa-CDD	20	90	57	82	72	100	47	42	55	74	84	40	46
		Difference Between Amount Spiked and Amount Detected, Percent											
2378-TCDD	0.4	-13	0	-50	0	-25	-25	0	0	0	25	-25	0
Other TCDD	0	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Penta-CDD	0	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Hexa-CDD	1.6	-39	0	-31	-13	-6.3	-50	-25	-13	13	-31	-38	13
Hepta-CD	2.4	0.8	8.3	-17	25	-4.2	-8.3	38	50	-17	-21	21	-17
Octa-CDD	3.2	-16	3.0	-25	12	-6.3	-13	16	-3.1	-6.3	-13	-3.1	-22
2378-TCDF	0.4	15	-25	-25	25	0	0	25	25	125	100	0	0
Other TCDF	0	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Penta-CDF	0.8	-6.3	-13	-38	0	-38	-38	-13	0	-13	25	-38	-15
Hexa-CDF	1.6	19	6.3	-38	-25	-25	-50	-31	-25	6.3	-19	-44	-13
Hepta-CDF	2.4	-13	-4.2	-25	29	-8.3	-8.3	38	46	-29	-33	33	4.2
Octa-CDF	3.2	-3.1	-41	-25	19	-16	-13	16	-6.3	-6.3	-13	-3.1	-25

[a] Amount of compound spiked into each sample prior to extraction and analysis. Only half of the amounts shown for the unlabeled tetra- through hexa-CDD's and CDF's were spiked on the Site 12 sample.

NS = Compound was not spiked into this sample.

TABLE 7-9. ANALYSIS RESULTS FOR TIER 4 CDD/CDF LABORATORY BLANKS

Compound	Site 01	Site 02	Site 03	Site 04	Site 05	Site 06	Site 07	Site 08	Site 09	Site 10	Site 11	Site 12
	Surrogate Recoveries, Percent											
$^{37}Cl_4$-TCDD[a]	94	96	98	94	100	78	94	102	78	96	96	0
$^{13}C_{12}$-TCDD[a]	96	110	94	94	102	106	108	98	88	94	98	100
$^{37}Cl_4$-Hepta-CDD[b]	97	57	78	54	56	62	61	72	110	92	43	41
$^{13}C_{12}$-Octa-CDD[b]	88	56	84	65	85	46	63	88	100	89	42	40
	Amount Detected, Nanograms											
2378-TCDD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Other TCDD	NR	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Penta-CDD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Hexa-CDD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Hepta-CDD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Octa-CDD	ND	ND	ND	0.1	0.2	0.05	0.1	0.2	0.2	ND	0.1	0.2
2378-TCDF	NR	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Other TCDF	ND	ND	ND	ND	ND	ND	0.04	ND	0.3	ND	ND	ND
Penta-CDF	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Hexa-CDF	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Hepta-CDF	ND	ND	ND	ND	ND	ND	0.03	ND	ND	ND	ND	ND
Octa-CDF	0.5	ND	ND	ND	ND	ND	0.04	ND	ND	ND	ND	ND

[a] Spiked at 5 ng in each sample.
[b] Spiked at 20 ng in each sample.
ND = Not Detected. Minimum limits of detection ranged from 0.01 to 0.11 nanograms.
NR = Not Reported.

TABLE 7-10. ANALYSIS RESULTS FOR TIER 4 MODIFIED METHOD 5 FIELD BLANKS

Compounds	Site[c] 01	Site[c] 02	Site[c] 03	Site 04		Site 05		Site[c] 06	Site 07		Site 08		Site 09		Site[c] 10	Site 11		Site 12[d]
	Outlet	Outlet	Outlet	Inlet	Outlet	Inlet	Outlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Outlet	Inlet	Outlet	
Surrogate Recoveries, Percent																		
$^{37}Cl_4$-TCDD[a]	86	96	92	86	106	70	104	101	63	98	76	90	84	88	80	72	80	NA
$^{13}C_{12}$-TCDD[a]	96	86	102	92	102	101	89	94	78	98	92	92	92	102	90	72	88	NA
$^{37}Cl_4$-Hepta-CDD[b]	83	79	58	44	42	46	67	88	90	94	43	72	138	64	90	65	68	NA
$^{13}C_{12}$-Octa-CDD[b]	89	60	99	48	67	93	91	70	92	98	52	93	94	72	65	96	104	NA
Amount Detected Per Sample Train, Nanograms																		
2378-TCDD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA	0.1	ND	ND	NA
Other TCDD	ND	ND	ND	ND	ND	ND	ND	0.2	ND	0.3	ND	0.4	ND	ND	2.0	0.7	ND	NA
Penta-CDD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.2	ND	ND	0.3	0.7	ND	NA
Hexa-CDD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.2	ND	ND	7.5	1.6	ND	NA
Hepta-CDD	1.6	ND	0.3	ND	0.5	ND	ND	0.2	0.1	ND	ND	25.7	ND	0.3	7.3	2.6	ND	NA
Octa-CDD	18.5	2.9	1.0	0.8	1.0	0.3	ND	0.5	0.3	0.4	0.6	109.3	0.4	0.5	6.3	1.0	0.3	NA
2378-TCDF	NR	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA	2.6	ND	ND	NA
Other TCDF	ND	0.2	ND	0.2	ND	0.2	ND	0.2	ND	0.3	ND	0.3	0.6	0.6	29.2	4.7	ND	NA
Penta-CDF	ND	ND	ND	ND	ND	ND	ND	0.2	ND	ND	ND	ND	ND	0.3	21.0	3.6	ND	NA
Hexa-CDF	ND	ND	ND	ND	ND	0.2	ND	0.4	ND	ND	ND	1.4	ND	0.3	40.0	5.1	ND	NA
Hepta-CDF	1.9	ND	0.1	ND	ND	ND	ND	0.5	0.2	0.1	ND	5.2	ND	ND	16.1	4.6	ND	NA
Octa-CDF	3.4	ND	ND	ND	ND	ND	ND	0.4	0.2	0.1	ND	3.5	0.2	0.2	43.1	1.2	ND	NA

[a] Spiked at 5 ng in each sample.

[b] Spiked at 20 ng in each sample.

[c] Sampling was conducted at the outlet of the control device only.

[d] Field blank data for Site 12 has not been analyzed.
ND = Not Detected. Minimum limits of detection ranged from 0.012 to 0.65 nanograms.
NR = Not Reported.
NA = Not Analyzed.

sample locations. The source of the Site 08 field blank contamination is not known, but there is no indication that other samples from this site were similarly contaminated.

Surrogate recoveries for flue gas MM5 samples are presented in Table 7-11. Recovery of the four labeled surrogate compounds satisfied QA requirements for all samples except the inlet MM5 samples from Sites 11 and 12 and the outlet MM5 samples from Sites 06 and 10. Surrogate recoveries for Sites 06 and 10 (outlet), and 11 and 12 (inlet), were below the target range of 40 to 120 percent. Problems with method efficiency for the Sites 06, 11 and 12 samples resulted from contamination present in the sample extracts and corresponding difficulties in achieving acceptable chromatographic separations. Problems with method efficiency for Site 10 were due to the large amounts of CDD's and CDF's present in the MM5 samples. Analytical results reported for MM5 samples from Sites 06 and 10 (outlet only) and 11 and 12 (inlet only) must be considered estimated values. Actual flue gas CDD/CDF concentrations are probably higher than those determined based on the reported results.

7.3.2 Ash CDD/CDF Analyses

Data available to assess uncertainty in the ash CDD/CDF concentration measurements include the audit results discussed in Section 7.3.1, fortified QC samples, and sample surrogate recoveries.

Fortified QC results and sample surrogate recoveries are presented in Tables 7-12 and 7-13, respectively. For the fortified ash QC samples, results are not reported for each site because samples were subjected to extraction and clean-up procedures as a "set" of 10, 11, or 12 samples. QA samples were then incorporated into each set. The QC ash sample results presented in Table 7-12 satisfy the QA requirements of ± 50 percent with the exception of hexa-CDF in the Site 06 sample and 2378-TCDF in Site 07 and Site 10 ash QC samples.

The spiked surrogate recoveries are shown in Table 7-13. The surrogate recoveries satisfied the QA requirements of 40 to 120 percent with the exception of low values for one baghouse sample at Site 07, and one bottom ash sample at Site 13. Because triplicate runs were performed at these

TABLE 7-11. SPIKED SURROGATE RECOVERIES FOR TIER 4 FLUE GAS CDD/CDF SAMPLES

			Surrogate Recovery, Percent			
Test Site	Test Run	Sample Location[a]	$^{37}\text{Cl}_4$-TCDD[b]	$^{13}\text{C}_{12}$-TCDD[b]	$^{37}\text{Cl}_4$-Hepta-CDD[c]	$^{13}\text{C}_{12}$-Octa-CDD[c]
01	09	Outlet	98	100	89	89
	10		100	98	85	83
	11		96	100	84	76
02	01	Outlet	96	98	88	73
	02		94	92	81	68
	03		96	88	98	54
	04		102	82	86	41
03	01	Outlet	78	106	48	99
	03		92	94	52	79
	05[d]		106	NS	53	NS
	05[e]		NS	102	NS	78
04	01	Outlet	94	88	47	49
	02		85	91	34	51
	03		100	98	48	63
	01	Inlet	90	90	55	76
	02		100	106	40	66
	03		96	62	53	42
05	01	Outlet	96	100	60	79
	02		96	77	54	64
	03		104	94	55	62
	01	Inlet	96	97	55	76
	02		107	101	63	66
	03		86	80	39	28
06	01	Outlet	13	80	0	18
	02		10	36	0	11
	04		5	76	20	4
	05		92	96	53	61
	03	(liquid)	0	NS	0	NS
	03	(particulates)	NS	76	NS	115
	03	(XAD & filter)	NS	54	NS	10
	06	(liquid)	0	NS	0.2	NS
	06	(particulates)	NS	66	NS	81
	06	(XAD & filter)	NS	0	NS	0
07	01	Inlet	52	52	4	6
	02		112	106	78	66
	03		88	88	48	64
	01	Outlet	92	96	75	58
	02		108	112	54	41
	03		104	114	66	40
08	01	Inlet	100	94	69	56
	02		84	68	74	65
	03		84	66	74	66
	01	Outlet	96	96	42	59
	02		96	96	55	62
	03		100	92	58	42
09	01	Inlet	70	96	114	84
	02		80	86	122	66
	03		92	94	102	64
	01	Outlet	84	90	80	82
	02		82	80	116	77
	03		68	94	90	105
10	02	Outlet	0	0	0	0
	03		0	120	0	58
	04		0	0	0	33
11	01	Inlet	84	66	0	11
	02		76	68	0	98
	03		92	106	26	28
	01	Outlet	94	100	45	40
	02		102	88	47	41
	03		94	96	52	42
12	01	Inlet	NS	0	0	0
	02		NS	90	25	14
	03		NS	94	42	26
	01	Outlet	NS	98	42	40
	02		NS	112	68	46
	03		NS	112	40	43
13	01	Outlet	0	0	0	
	02		0	0	0	
	03		0	0	0	

[a] Emission control device inlet or outlet test location.

[b] Spiked at 5 ng in each sample.

NS = Compound was not spiked into this sample.

[c] Spiked at 20 ng in each sample.

[d] Aqueous portion

[e] XAD-2 resin portion

TABLE 7-12. ANALYSIS RESULTS FOR FORTIFIED ASH QUALITY CONTROL SAMPLES

	Site 04	Site 06	Site 07	Site 10	Site 12
$^{13}C_{12}$-TCDD[a]	91	97	102	92	98
$^{13}C_{12}$-OCDD[b]	85	58	90	57	54
Difference between Amount Spiked and Amount Detected, Percent					
2378-TCDD	-50	45	-25	0	0
Hexa-CDD	-25	48	0	-32	19
Hepta-CDD	17	25	4	-21	21
Octa-CDD	6	44	9	-9	13
2378-TCDF	-50	20	-75	125	0
Penta-TCDF	13	50	0	13	0
Hexa-CDF	-25	54	13	-25	25
Hepta-CDF	17	21	8	21	-25
Octa-CDF	7	41	19	-6	16

[a] Spiked at 5 ng in each sample.
[b] Spiked at 20 ng in each sample.

TABLE 7-13. SPIKED SURROGATE RECOVERIES FOR TIER 4 ASH SAMPLES

Test Site	Test Run	Ash Type	Surrogate Recovery, Percent $^{13}C_{12}$-TCDD[a]	Surrogate Recovery, Percent $^{13}C_{12}$-Octa-CDD[b]
01	09	Furnace	90	91
	10	Furnace	82	88
	11	Furnace	78	86
02	01	Bottom	99	43
	03	Bottom	100	56
	04	Bottom	94	69
03	03	Scrubber water solids	84	63
	04	Scrubber water solids	98	73
04	Presurvey	Economizer	89	93
06	1	Primary chamber	78	51
	2	Primary chamber	110	70
	3	Primary chamber	71/100[c]	44/54[c]
	2	Settling chamber	94	85
	3	Settling chamber	100	66
07	1	Primary chamber	92	42
	3	Primary chamber	62	44
	1	Secondary chamber	60	46
	2	Secondary chamber	89	61
	3	Secondary chamber	62	54
	1	Baghouse	99	26
	2	Baghouse	89	49
	3	Baghouse	90	53
08	01	ESP	96	54
	02	ESP	98	56
	03	ESP	94	62
09	01	Baghouse	86	51
	02	Baghouse	94	73
	03	Baghouse	116	78

(Continued)

TABLE 7-13. SPIKED SURROGATE RECOVERIES FOR TIER 4 ASH SAMPLES (Continued)

10	02	#1 Baghouse dust	100	73
	02	#2 Baghouse dust	102	56
	03	#1 Baghouse dust	104	63
	03	#2 Baghouse dust	90	64
	04	#1 Baghouse dust	96	64
	04	#2 Baghouse dust	68	45
11	01	Furnace outlet	61	0[d]
	02	Furnace outlet	50	42
	01	Furnace outlet	88	0[d]
12	01	Filterable scrubber solids	102	46
	02	Filterable scrubber solids	98	48
	03	Filterable scrubber solids	106	54
	01	Bottom	98	74
	02	Bottom	86	67
	03	Bottom	84	63
13	01	Bottom	94	68
	02	Bottom	93	72
	03	Bottom	99	25

[a] Spiked at 5 ng in each sample.
[b] Spiked at 20 ng in each sample.
[c] Duplicate samples
[d] Contaminated samples

sites, the low surrogate recoveries for these single samples were not expected to affect the results. For Site 11, the furnace ash samples from Run 01 did not show any surrogate recoveries because of sample contamination.

7.3.3 Feed CDD/CDF Precursor Analyses

CDD/CDF precursors analyzed in the feed samples include chlorobenzenes (CB), chlorophenols (CP), chlorinated biphenyls (PCB), total elemental chlorine and total halogenated organics (TOX). Data available to assess uncertainty in the CB, CP and PCB analyses include lab blanks and sample surrogate recoveries. Data available to assess the quality of the chlorine analyses include lab blanks and QC samples.

Surrogate recoveries for the CB, CP and PCB analyses are reported for feed samples in the site specific test reports for the Tier 4 program. These results will not be repeated in this section. In general, the surrogate recoveries for the CB, CP and PCB analyses were below the QA objective of 50 percent and the reported analytical results must be considered as estimates. Where measurable concentrations of CB, CP and PCB were found in the feed samples, the actual values are probably three or more times greater than the reported value.

There are several reasons for the comparatively low precursor surrogate recoveries reported for the Tier 4 feed samples. First, the complex nature of the samples required extensive clean-up procedures prior to GC/MS analysis, which increased the potential for losses of the surrogate compounds (and analytes) during sample preparation. There were no standard extraction/analysis procedures available for the specific sample types to be analyzed. And, although attempts were made, ideal procedures could not be developed for all sample types in the time frame available. Second, large sample sizes (25 to 50 gram) were required to increase method sensitivity for the target analytes and to ensure that representative portions of the samples were analyzed. Due to the high cost of labeled surrogates, it was not desirable to spike the large sample sizes with surrogates in proportion to that normally used for smaller samples. Results of supplemental laboratory studies are shown in Table 7-14. These data show that when

TABLE 7-14. COMPARISON OF PERCENT SURROGATE RECOVERIES FOR LARGE AND SMALL SAMPLE SIZES[a]

Compound	Blanks		Site 12 Sludge Feed		Site 05 Strong Black Liquors		Site 09 Spent Carbon Feed		Site 02 Paint Sludge		Site 02 Wood/ Plastic Parts	
			50g	1g	50g	1g	50g	1g	50g	1g	50g	1g
d_6-phenol	25	36	4	32/31	3	32	15	32	11	34	18	40
d_4-2-chlorophenol	77	59	6	55/40	9	47	25	42	12	59	30	59
$^{13}C_6$-pentachlorophenol	60	68	9	77/59	13	20	ND	37	6	74	36	93
d_4-dichlorobenzene	43	85	20	25/47	73	52	24	52	ND	25	ND	44
bromobiphenyl	116	117	29	80/97	91	86	63	85	ND	96	10	82
tetrabromobiphenyl	111	117	16	101/113	74	88	53	85	ND	101	35	73

[a] Large samples consisted of 50g and small samples consisted of 1g. The same quantity of surrogates (200 ng) was spiked on both samples sizes.

sample size was restricted to 1 gram and the amount of surrogate spiked was held fixed, surrogate recoveries improved substantially.

In spite of the relatively low surrogate recovery values for some of the feed samples, the resulting analytical sensitivity for the target analytes was considered acceptable for the purpose of this study. The instrumental detection limit ranged from about 100 to 500 picograms on-column for the 1 microliter of final extract injected into the GC/MS. At a method recovery efficiency of 100 percent for a 50 gram solid sample cleaned up to a final extract volume of 1 milliliter, the overall analytical sensitivity would be approximately 2 to 10 ppb in the solid sample. For samples with surrogate recoveries as low as 1 percent, the overall analytical sensitivity of the method would still be 200 to 1,000 ppb, or 0.2 to 1.0 ppm. Thus, even in a worst-case situation the analytical procedures used provide information on the precursor content of the feed samples down to the ppm level.

Results from laboratory blanks for the CB, CP and PCB analyses showed no detectable target compounds at a detection limit of 10 ppb.

Total chloride analyses were performed by Research Triangle Institute. Blank analysis values obtained for the Parr bomb combustion/ion chromatography technique were 36, 0, 56, and 18 ppm chloride. A commercially available coal standard containing 2,600 ppm chloride was analyzed as a daily QC standard. Reported values were 2,500, 2,500, 2,500 and 2,400 ppm.

Quality control for the total organic halide (TOX) data consisted of a single QC sample analysis. The sample contained 2-chlorophenol and pentachlorophenol at a TOX level of 376 ppm. The total TOX measured for the sample was 251 ppm, showing 67 percent recovery.

7.3.4 Flue Gas Combustion Parameters Monitoring

Continuous emissions monitoring (CEM) of flue gas CO, CO_2, O_2, NO_x, SO_2, and total hydrocarbons (THC) was performed at most of the Tier 4 test sites. The purpose of the CEM data was to 1) observe fluctuations in flue gas parameters, and 2) provide an indication of combustion conditions. Data available to assess the quality of the continuous monitoring efforts include

1) performance audit results, 2) drift check results, and 3) quality control data.

The results of the CEM performance audit are presented in Table 7-15. Generally, the audit results showed the CEM instrumentation to be calibrated well within the specified program accuracy objectives. There were two exceptions. The CO/CO_2 instrument exhibited a high signal to noise ratio and high bias for both channels with the CO channel exceeding the ±20 percent accuracy target by a small margin. There was a degree of non-linearity below 70 ppm CO; however the majority of actual testing data was above 1000 ppm. Also the NO_x instrument showed a high response bias exceeding the ±20 percent accuracy target for this parameter. Both instruments had a linear response across the scale (correlation coefficient, $r \geq 0.9950$).

Accuracy problems resulting from the high signal-to-noise ratio for the CO/CO_2 instrument were reduced for sites tested after the performance audit (Site 03) by an improved data acquisition system. The new system collected integrated one minute data as opposed to instantaneous one minute values. Data for CO concentrations at the sites using the original data acquisition system should be flagged as possibly having a high bias (>20 percent). The NO_x instrument was repaired following the audit and no further problems were encountered with this instrument.

Pre- and post-test analysis of mid-point calibration standards were used to track daily instrument drift for each of the different parameters. The mean percent drift for each parameter is presented in Table 7-16 and ranged from -0.121 to 5.943 percent, well within the ±10 percent acceptance criterion for instrument drift. The extreme cases were the O_2 and SO_2 instruments exhibiting average or mean drifts of -0.121 and 5.943 percent respectively. Data showing instrument drift for each of the 13 test sites are presented in Figure 7-1.

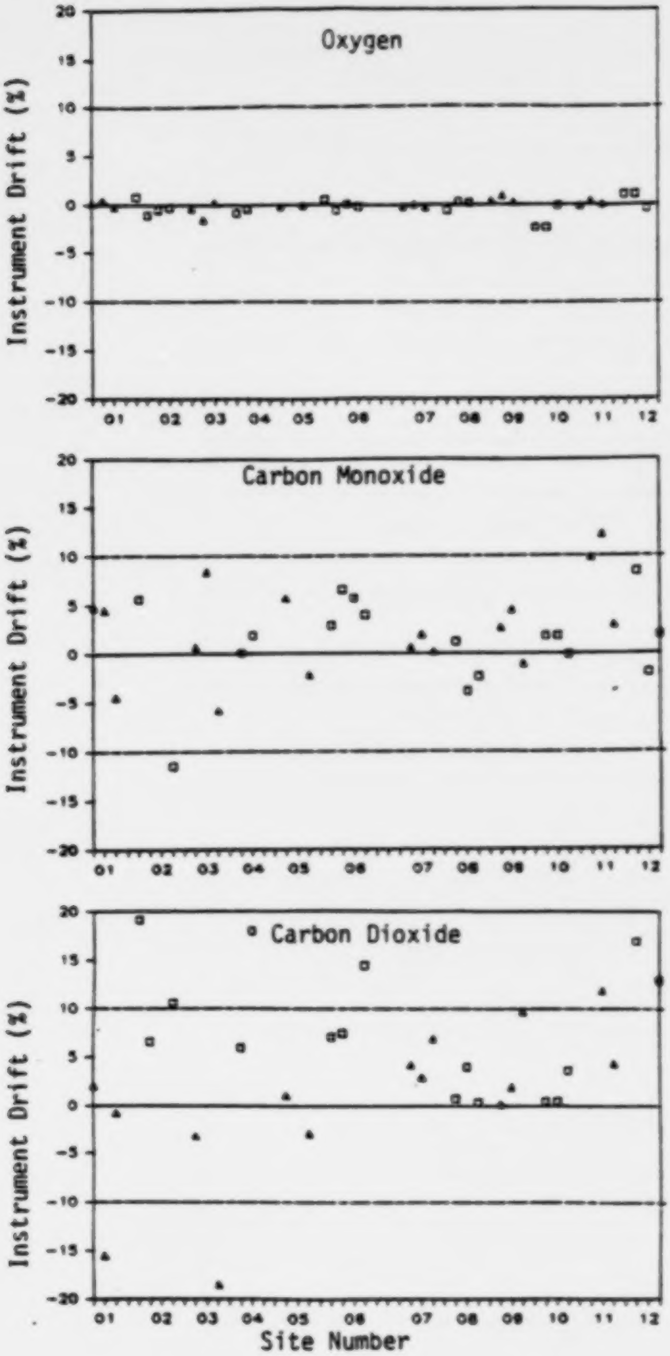
Day-to-day variability for the continuous emission monitors was determined by daily (pre-test) analysis of a control standard. Acceptability of the QC check was based on agreement of the daily analysis result with the average concentration measured for the QC standard on

TABLE 7-15. CONTINUOUS EMISSION MONITORING SYSTEM (CEM) AUDIT RESULTS

Parameter	Input Concentration (ppm)	Measured Concentration (ppm)	Relative Error (%)	Accuracy Target (%)
CO	0.0	-0.8	-	±20
	60.5	115.4	90.7	
	259.0	325.9	25.8	
	1002.0	1239.5	23.7	
	2491.0	2933.8	17.8	
	2480.0	3048.4	22.9	
CO_2	0.00	0.45	-	±20
	2.01	2.16	7.5	
	7.61	8.99	18.1	
	10.50	12.01	14.4	
O_2	0.0	-0.05	-	±20
	4.02	4.23	5.3	
	7.99	8.40	5.1	
	9.96	10.34	3.8	
NO_x	0.0	1.3	-	±20
	51.7	62.6	21.1	
	100.0	121.5	21.5	
	225.0	279.5	24.2	
	705.0	795.9	12.9	
THC	0.0	1.11	-	±25
	9.63	9.84	2.2	
	20.50	19.50	-4.9	
	80.40	75.16	-6.5	

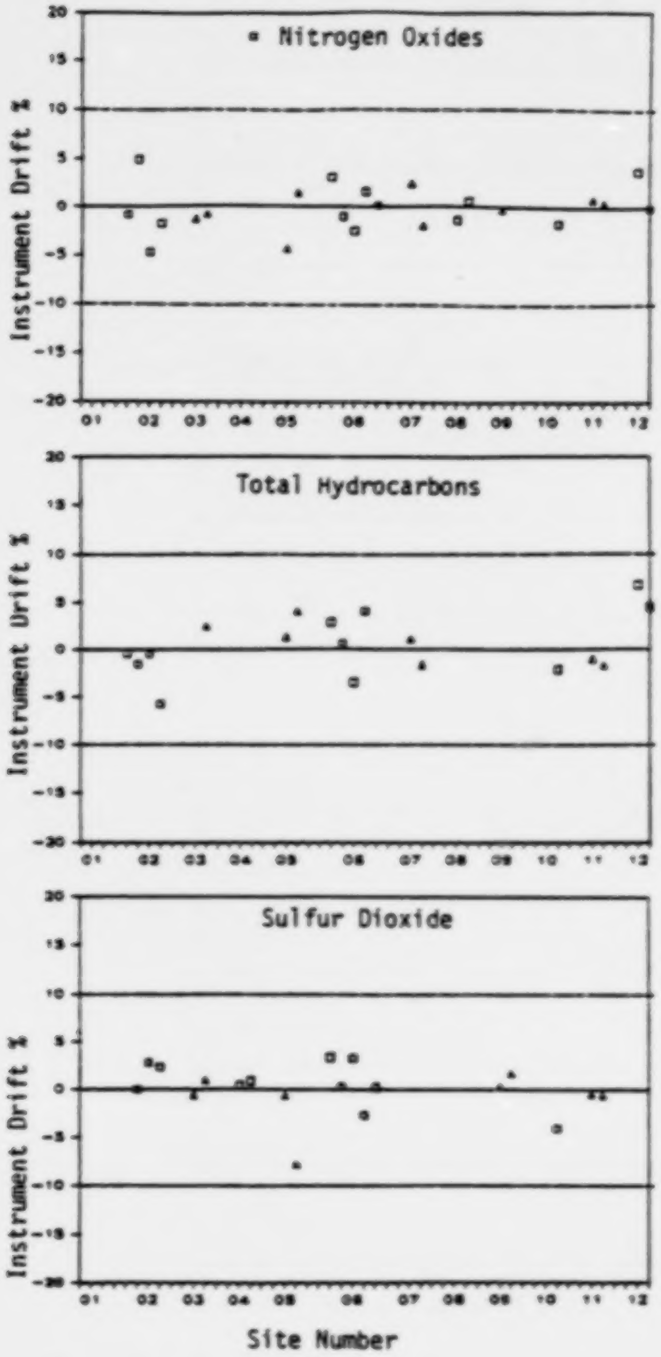
TABLE 7-16. SUMMARY OF INSTRUMENT DRIFT CHECK RESULTS FOR FLUE GAS PARAMETERS

Parameter	Average Drift (%)	Standard Deviation
O_2	-0.121	0.758
CO	2.016	8.514
CO_2	5.572	10.463
SO_2	5.943	8.515
NO_x	4.861	12.073
THC	4.689	7.186



Notes: Square represents even numbered sites; triangle represents odd numbered sites. Drift check acceptance criterion was ± 10% drift.

FIGURE 7-1. DRIFT CHECK RESULTS FOR CEM PARAMETERS



Notes: Square represents even numbered sites; triangle represents odd numbered sites. Drift check acceptance criterion was ± 10% drift.

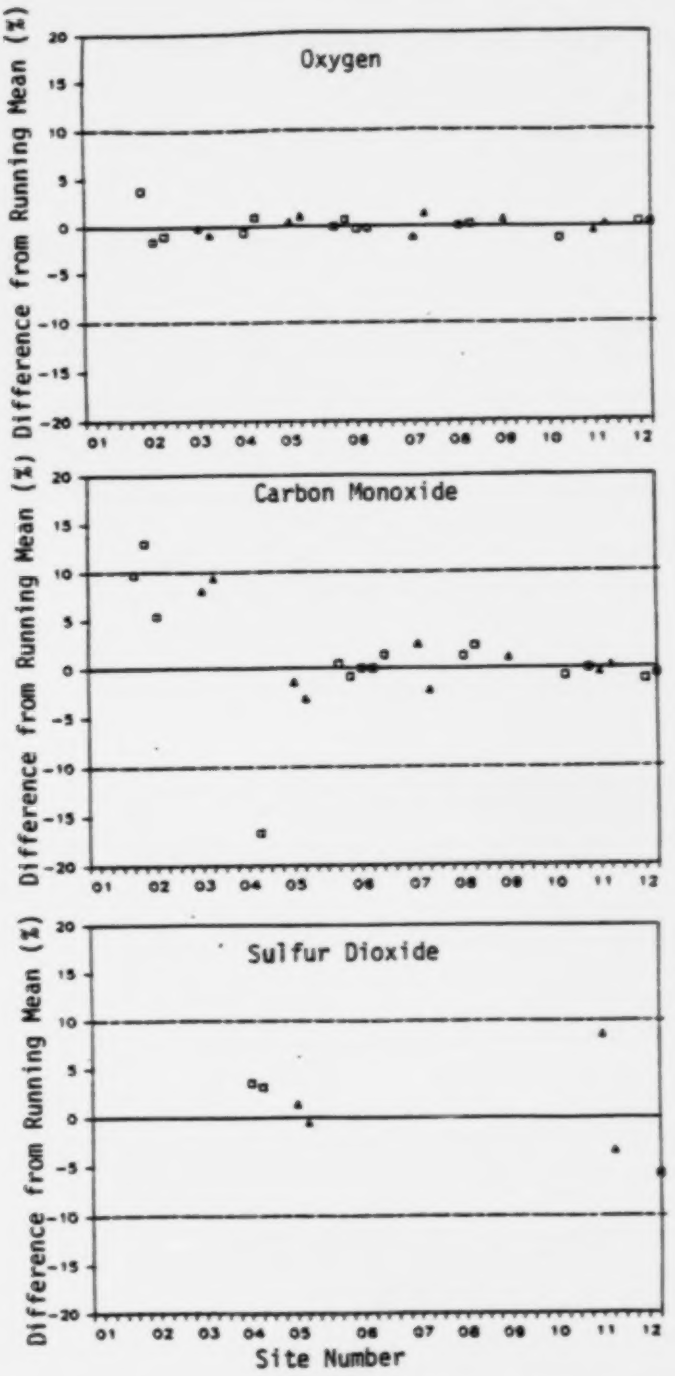
FIGURE 7-1. DRIFT CHECK RESULTS FOR CEM PARAMETERS (continued)

previous test days at that test site (i.e., the running mean concentration). Table 7-17 summarizes the results of these QC checks. The average percent difference from the running mean for the 13 sites ranged from -0.016 to 0.993 percent and only two percent of the QC checks fell outside the control limits of ±10 percent of the running mean. Data showing the QC check results for the 13 sites are presented in Figure 7-2.

TABLE 7-17. SUMMARY OF QUALITY CONTROL STANDARD ANALYSES FOR FLUE GAS PARAMETERS

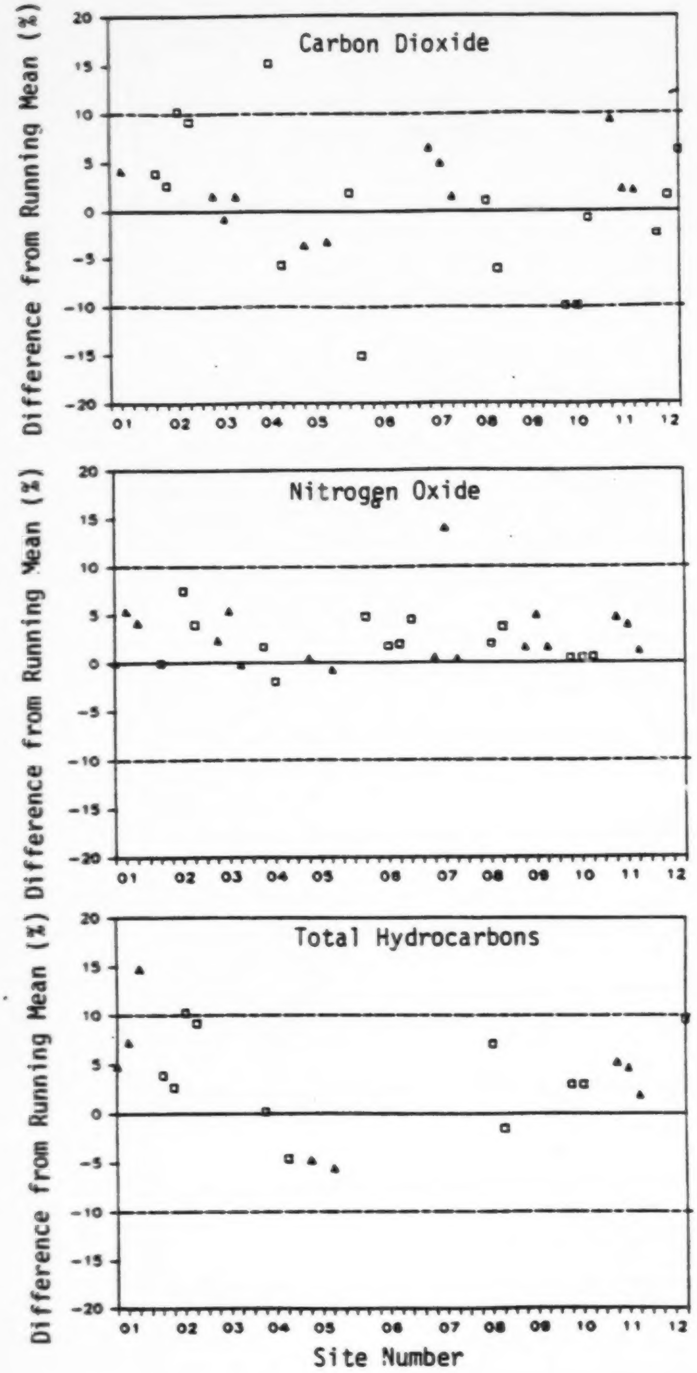
Parameter	Average Difference from Running Mean (%)[a]	Standard Deviation
O_2	0.146	1.079
CO	0.307	6.821
CO_2	0.644	4.209
SO_2	0.993	4.391
NO_x	0.538	3.081
THC	-0.016	2.571

[a] Average based on Sites 01 through 13. Running mean determined separately for each site based on consecutive daily analyses of the quality control standard.



Notes: Square represents even numbered sites; triangle represents odd numbered sites. Control standard acceptance criterion was difference from running mean within ± 10%.

FIGURE 7-2. CONTROL STANDARD ANALYSIS RESULTS FOR CEM PARAMETERS



Notes: Square represents even numbered sites; triangle represents odd numbered sites. Control standard acceptance criterion was different from running mean within ± 10%.

FIGURE 7-2. CONTROL STANDARD ANALYSIS RESULTS FOR CEM PARAMETERS (continued)

CHAPTER 8
ASH SAMPLING PROGRAM

8.1 OVERVIEW OF THE ASH SAMPLING PROGRAM

The ash sampling program had two major goals. First, for ash samples collected at the source test sites, the intent of the ash sampling program was to relate CDD/CDF concentrations in the ash to CDD/CDF concentrations in the flue gas. Rank order statistical analyses were used to determine statistically significant relationships between the CDD/CDF concentrations in the ash and flue gas. The hypothesis was if significant relationships between the ash and flue gas emissions were found, then ash sampling could potentially be used as a quick and relatively inexpensive method for qualitatively screening combustion devices for possible CDD/CDF emissions in the flue gas. The second major goal was to use the results of the ash sampling program as the basis for re-evaluating the ranking of source categories as potential emitters of CDD/CDF.

Previous to this study, several studies, as discussed in the Initial Literature Review, had initially attempted to assess CDD/CDF emissions by taking ash samples only. However, differences in analytical methods, sampling methods, congeners reported, and limited process information for the CDD/CDF data from these studies caused comparisons of these results to be questionable. Therefore, additional investigation was considered necessary.

The use of ash samples for screening combustion sources has several advantages:

1. There is usually a significant quantity of easily accessible ash in the hoppers of the control devices on combustion sources.
2. The fly ash is usually homogeneous and can be readily extracted without complex sample preparation techniques.
3. Ash sampling does not require sophisticated sampling equipment.
4. Ash sampling supplies and samples can be shipped easily.

5. A PCDD/PCDF (tetra- through octa- congeners) analysis can be performed for approximately $500 to $1,000.

The main disadvantage of using ash screening as a means of assessing CDD/CDF emissions in the flue gas is the lack of data to qualitatively support the relationship. Work previous to the Tier 4 Study had not demonstrated ash sampling to be a proven, reliable screening technique.

For the Tier 4 ash sampling program, ash samples were collected from a range of combustion devices at sites located across the United States. The types of ash sampled included baghouse ash, multicyclone ash, electrostatic precipitator ash, afterburner ash, settling chamber ash, economizer ash, particulates filtered from scrubber water and bottom ash. If possible, the ash was sampled at a point in the process where the particulate matter was the finest and coolest because semivolatiles like PCDD/PCDF are expected to condense on cool, fine particulate. Thus, the sampling point was usually the farthest accessible point downstream of the process or control device. Bottom ash was collected from uncontrolled combustion devices or where control device ash sampling was not practical. At some sites, ash samples were taken from multiple sampling locations in a process (e.g., bottom ash and scrubber water filterable solids for a sewage sludge incinerator). If available from plant instrumentation, process data such as feed rate, feed composition and flue gas characteristics such as temperature, oxygen content, and carbon monoxide content were also collected for each site where ash samples were collected.

Ash samples were collected from 75 sites (including CDD source test sites) located in 21 states and in eight EPA regions. Twenty-two combustion source categories were included with one to nine sampling sites in each category. The target number of ash sites for each category was three. More samples were obtained for some categories because EPA Regional offices requested more sites (e.g., wood-fired boilers) or several pre-test surveys were done for the emissions testing program (e.g., sewage sludge incinerators and black liquor boilers). For some of the Rank C source categories, fewer than three sites were sampled because only one or two sites were identified for sampling. Table 8-1 summarizes the ash sampling sites.

TABLE 8-1. SUMMARY OF ASH SAMPLING SITES

Combustion Device Category	Radian Site Code	Sample Type Solid/Slurry	Sampling Organization[a]
Sewage Sludge Incinerator	SSI-A	Bottom Ash	Radian/Source Test
	SSI-B	Bottom Ash	Radian/Source Test
	SSI-C	Filterable Solids Filtrate Bottom Ash	Radian/Source Test
	SSI-D	Scrubber Water	Radian/Region V
	SSI-F	Filterable Solids Filtrate	Radian site survey
	SSI-G	Bottom Ash	Radian site survey
	SSI-H	Bottom Ash	Radian site survey
	SSI-I	Bottom Ash	Radian site survey
	SSI-J	Scrubber Solids	Radian site survey
Black Liquor Boiler	BLB-A	Economizer Ash	Radian site survey
	BLB-C	ESP Ash	Radian/Source Test
	BLB-D	ESP Ash	Radian site survey
	BLB-E	ESP Catch	Radian/Region V
	BLB-F	Economizer Ash	Radian site survey
	BLB-G	ESP Ash	CARB
Wire Reclamation Incinerator	WRI-A	Settling Chamber Ash Primary Chamber Ash	Radian/Source Test
	WRI-B	Baghouse Dust	Radian site survey
	WRI-C	Settling Chamber Ash	Radian site survey
	WRI-D	Fly Ash/afterburner	Radian/Region V
Secondary Copper Recovery	MET-A	Baghouse Ash	Radian/Source Test
	MET-B	Baghouse Dust	Radian site survey
Carbon Regeneration Furnace	CRF-B	Baghouse Dust	Radian/Source Test
	CRF-B	Filterable Solids Filtrate	Radian/Region III
	CRF-C	Afterburner Ash	Radian/Region III
Wood-fired Boiler	WFB-A	Baghouse Dust Bottom ash	Radian/Source Test
	WFB-B	Dust	EPA Region X
	WFB-C	Baghouse Dust	Radian site survey
	WFB-D	Scrubber Water	Radian/Region V
	WFB-E	Multiclone Ash	CARB
	WFB-F	Multiclone Ash	CARB
	WFB-G	Multiclone Ash	CARB
	WFB-H	Multiclone Ash	CARB
Drum and Barrel Reclamation Incinerator	DBI-A	Bottom Ash	Radian site survey
	DBR-A	Bottom Ash	Radian/Source Test
	DBI-C	Bottom Ash	Radian site survey
	DBI-D	Bottom Ash	EPA Region V
	DBI-E	Bottom Ash	Radian/Region V

(Continued)

TABLE 8-1. SUMMARY OF ASH SAMPLING SITES (Continued)

Combustion Device Category	Radian Site Code	Sample Type Solid/Slurry	Sampling Organization[a]
Hazardous Waste Incinerator	HWI-A	Bottom Ash	Radian/Region V
	HWI-B	Scrubber Water	Radian/Region V
	HWI-C	Scrubber Water	Radian/Region V
Hospital Waste Incinerator	WIH-A	Bottom Ash	Radian/Region V
	WIH-B	Fly Ash	Radian/Region V
	WIH-C	Bottom Ash	CENTEC
	WIH-D	Primary Ash	MDEQE
Open Burn	OB-A	Flyash	OSDA
	OB-B	Ash	FDER
Sulfite Liquor Boiler	SLB-A	Filterable Solids	EPA Region X
	SLB-B	Filterable Solids Scrubber Water	Radian/Region V
	SLB-C	Solids/Filtrate Bottom ash	EPA Region V
Woodstove	WS-A	Bottom Ash	Radian
	WS-B	Bottom Ash	Radian
	WS-C	Bottom Ash	RTI-Radian/Source Test
Spreader Stoker Boiler	SSB-A	Multi-Clone Ash	EPA Region IV
	SSB-B	Multi-Clone Ash	Radian
	SSB-C	Bottom Ash Multi-clone ash	SODHEC
Commercial Boiler	CB-A	Multi-Clone Ash	EPA Region IV
	CB-B	Fly Ash	Memphis & Shelby County Health Department
Utility Boiler	UB-A	Baghouse Dust	Radian
	UB-B	ESP Catch	Radian/Region V
	UB-D	Bottom Ash	Radian
Apartment House Incinerator	AHI-A	Bottom Ash	Hamilton County APCB
	AHI-B	Bottom Ash	CENTEC
	AHI-C	Bottom Ash	CENTEC
	AHI-D	Bottom Ash	CENTEC
Charcoal Manufacturing	CM-A	Afterburner Ash/ Boiler Fly Ash	SODHEC
	CM-B	Bottom Ash	Region VII
Cement Kiln	CK-A	ESP Catch	Radian/Region V
	CK-B	ESP Catch	Radian/Region V

(Continued)

TABLE 8-1. SUMMARY OF ASH SAMPLING SITES (Continued)

Combustion Device Category	Radian Site Code	Sample Type Solid/Slurry	Sampling Organization[a]
Municipal Solid Waste Incinerator	MSWI-A	ESP Catch	Radian/Region V
	MSWI-B	Bottom Ash Filtered solids Filtrate Scrubber water	Radian/Region V
	MSWI-C	ESP Catch Scrubber water	Radian/Region V
	MSWI-D	ESP Catch	Radian/Region V
Briquet Charcoal Grill	BC-A	Bottom Ash Uncombusted Charcoal	EPA/OAQPS
Industrial Solid Waste Incinerator	ISW-A	Bottom Ash	Radian/Source Test
Rotary Kiln Dryer	ADK-A	Baghouse Dust	CARB

[a]CARB = California Air Resources Board
CENTEC = EPA Region II
MDEQE = Massachusetts Department Environmental Quality Engineering
OSDA = Oregon Department of Agriculture
FDER = Florida Department of Environmental Regulation, Bureau of Air Quality Management
SCDHEC = South Carolina Department of Health and Environmental Control
Hamilton County APCB = Hamilton County Air Pollution Control Board (Tennessee)

8.2 PREVIOUS WORK

Previous work has not demonstrated ash sampling to be a proven, reliable screening technique to provide conclusive estimates of CDD emissions in the flue gas from combustion sources. A summary of the ash data available in the literature was presented previously in Table 3-2.

A considerable fraction of CDD emissions is hypothesized to be present in the gas phase or adsorbed onto the fine particulate. If this is true, CDD would generally not be concentrated in bottom ash or fly ash collected in an air pollution control device. Data are available that indicate there is likely to be selective partitioning of homologues between the flue gas and the particulate matter (fly ash and bottom ash).[41] These data imply that tetra chlorinated CDD's concentrate in the flue gas, while the more chlorinated CDD homologues concentrate in the particulate matter.

Another study has shown that PCDD's tend to be enriched on smaller particles.[116] Small particles may not be captured by some control devices and may be emitted from the source.

A third study has suggested that the absence of TCDD's in the ash samples does not guarantee the absence of TCDD's in the flue gas. At one source, where both stack and ash data were collected, tetrachlorinated CDD's were found in the flue gas, but no tetra through octa chlorinated CDD's were found in the fly ash (i.e., a "false negative" condition).[220]

Table 8-2 shows flue gas and fly ash analyses for several combustion categories where both types of samples were taken. The data suggest that PCDD ash analysis may be a useful indicator of the presence of TCDD emissions. However, based upon these data there is no quantitative relationship between the PCDD content of the ash samples and the PCDD concentrations in the flue gas emissions.

8.3 ASH SAMPLING SITE SELECTION

The objective of the ash sampling site selection effort was to select sites in combustion categories with potential for CDD/CDF emissions. Also, at least three sites were selected within each category, if possible.

TABLE 8-2.
COMPARISONS OF FLUE GAS AND FLY ASH DIOXIN AND DIBENZOFURAN CONTENTS

Source Category	Reference #	Stack (ng/m^3)		ESP Ash (ng/g)	
		PCDD	PCDF	PCDD	PCDF
Municipal Solid Waste	43 (Italy #2)	48,997	-	599.9	-
	43 (Italy #3)	7509.9	-	7.32	-
	43 (Italy #4)	4409.4	-	3537.2	-
	43 (Italy #5)	1030	-	0.878	-
	43 (Italy #6)	587.8	-	5.86	-
	49 (Canada)	107	143	31[a] 0[b] 1307[c]	13[a] 0[b] 161[c]
	92 (Hampton, VA)	2,284	11,000	800	3,000
	168 (Philadelphia) NW #1	2,366	2,533	1,975	1,500
	168 (Philadelphia) NW #2	745	775	1,333	1,066
	178 (Zaanstad)	1257.7	1116.5	5,173	2080.6
	181 (Ontario)	2,687	-	23	46.75
Hospital Incinerator	31A (Canada)	69	155.6	3,369[d] 1.6[e] 2.7[f]	3,068[d] 3.6[e] 11.2[f]
Boilers Co-firing Waste	41	76.5	-	48.6[g]	-
Carbon Regeneration	13 (Cincinnati, OH)	47.7[h]	103[h]	2.2[h,i]	1.7[h,i]

[a] Economizer ash.
[b] Incinerator ash.
[c] Boiler ash.
[d] Fly ash from duct between the low temperature stack and heat exchanger.
[e] Combustion chamber ash.
[f] Bottom ash.
[g] Furnace ash.
[h] TCDD/TCDF scan only.
[i] Cyclone ash.

The following factors were considered in ranking source categories for ash sampling:

a. PCDD in feed,
b. precursors in feed,
c. chlorine in feed,
d. combustion temperature,
e. residence time,
f. oxygen availability,
g. feed processing,
h. supplemental fuel,
i. valid testing already performed,
j. size of source category.

Details of the ranking process were discussed in Chapter 4. Also, sites in the Rank C and Rank D categories were included in order to expand the CDD/CDF data base for these categories. Table 8-3 presents the final ranking of the combustion device categories which was used in selecting the sites for the ash sampling program. Also included in the table are the number of sites from which samples were collected for each category. The most ash samples were collected from Rank A and Rank B categories.

The combustion category rankings and specific selection criteria for each combustion source category are presented in Table 8-4. These category rankings and specific selection criteria were sent to EPA Regional Offices who provided inputs regarding the potential sampling sites. The Regional Offices were asked to complete a questionnaire for each site selected. These questionnaires detailed such information as feed material, feed rate, pollution control device, types of ash generated, potential for CDD and CDD precursors in the feed, combustion parameters and ease of sampling. The sites that were recommended by EPA Regional Offices were screened by OAQPS, and a mixture of sites believed to be generally "typical" of those in the rest of the category, and sites thought to have a greater than average potential for CDD emissions were selected for sampling.

TABLE 8-3. COMBUSTION SOURCE CATEGORIES SAMPLED IN ASH PROGRAM
(August, 1985)

Source Category	Number of Ash Sites
Rank A	
Sewage Sludge Incinerators	9
Black Liquor Boilers	6
Rank B	
Industrial Incinerators	1
Carbon Regeneration (industrial)	3
Wire Reclamation	4
Wood Boilers (firing PCP treated or salt-laden wood)	8
Drum and Barrel	5
Secondary Copper Smelters	2
Rank C	
Hospital Waste Incinerators	4
Charcoal Manufacturing	2
Wood Stoves	3
Small Spreader-Stoker Coal Boiler	3
Chlorinated Organic Waste Incinerators	3
Cement/Lime Kilns & Dryers Cofired w/Chlorinated Organic Wastes	3
Commercial Boilers Firing Fuels Contaminated with Chlorinated Organic Wastes	2
Open Burning	2
Apartment House Flue-fed Incinerators	3
Rank D	
Municipal Solid Waste (MSW) Incinerators	4
Industrial Boilers Cofiring Wastes (Utility Boilers)	3
Unranked	
Briquet Charcoal Grill	1
Sulfite Liquor Boilers	3
Residential Oil Burners Burning Waste Oil	1

Rank A - Large source categories (greater than 1 million tons of fuel and/or waste burned annually) with elevated dioxin precursor contamination or feed/fuel. These categories have a high potential to emit TCDD, and population exposure is expected to be relatively high compared to other source categories.

Rank B - Small source categories (less than 1 million tons of fuel and/or waste burned annually) or source categories with limited dioxin precursor contamination of feed/fuel. These categories have a high potential to emit TCDD, but population exposures are expected to be low.

Rank C - Source categories less likely to emit 2378-TCDD.

Rank D - Source categories which have been tested three or more times.

TABLE 8-4. SOURCE CHARACTERISTICS OF INTEREST FOR DIOXIN TEST PROGRAM

Source Category	Source Characteristics of Greater Interest
Apartment house incinerators	Units with a record of poor combustion conditions and excessive waste loading and/or burning waste oil.
Black liquor boilers	Paper pulp mills using wood stored in salt water prior to pulping and/or producing bleached paper where bleach effluents are combined with the black liquor.
Carbon regeneration furnace	Activated carbon used to treat industrial waste streams of chlorinated organics.
Cement/Lime kilns and dryers	Firing chlorinated organic wastes (e.g., Cl-phenols, Cl-benzenes).
Charcoal manufacturing	Using wood scrap treated with chlorinated organics.
Chemical sludge incinerators	Burning wastes containing chlorinated organics.
Commercial boilers	Burning chlorinated organic waste contaminated fuels.
Hazardous waste incinerators	Firing chlorinated organic wastes (e.g., Cl-phenols, Cl-benzenes).
Industrial boilers	Smaller than 50 million Btu/hr with a particulate control device.
Open Burning	Open burning of fields or wastes which have been treated with chlorinated organics.
Sewage sludge incinerators	All waste treatment plants servicing areas with industry manufacturing or using chlorinated organics.
Waste incinerators, hospitals	Burning chlorinated organics.
Wire reclamation incinerators	Burning PVC-coated wire or wire contaminated with PCB's.
Wood/bark boilers	Burning pentachlorophenol treated wood or salt-laden wood.

8.4 SAMPLE ACQUISITION

The ash samples were picked up from the selected sites by several different organizations including EPA Regional Offices, other local air quality agencies, OAQPS/EPA and Radian. Radian collected ash samples during source tests, source test pre-test surveys, and specific ash program pick-ups. Table 8-5 lists the specific sampling organizations and number of samples obtained by each organization.

To standardize the sampling procedure as much as possible, an ash sampling kit was developed and distributed to organizations picking up the ash samples. The ash sampling kits contained:

1. a copy of the ash sampling document,
2. two Tier 4-cleaned 950 ml amber glass bottles w/teflon lined lids,
3. sample labels, sample integrity seals and teflon tape to seal jar,
4. packing material to safely ship samples,
5. shipping labels and forms to ship samples back to Radian,
6. information on how to select ash sampling location and sampling procedure, and
7. a form detailing process information needs.

The samplers were asked to select a sampling location as far downstream from the combustion device as possible. Thus, pollution control device ash was preferred over bottom ash. Also, a sampling location before the ash had reached a storage bin was preferred (i.e., an ash outfall).

The types of ash that were collected included:

1. fly ash (settling chambers, economizers, afterburners),
2. baghouse ash,
3. ESP ash,
4. bottom ash,
5. multi-cyclone ash,
6. particulate filtered from scrubber water.

Scrubber water samples to be analyzed by Troika were first returned to Radian where they were filtered. The filterable solids and filtrate were then sent to Troika to be analyzed separately.

TABLE 8-5. SAMPLING ORGANIZATIONS FOR ASH SITES

Sampling Organization	Number of Sites Sampled
Radian	
Source Test Site Surveys	14
Source Tests	11
Subtotal	25
EPA Region II (CENTEC)	4
EPA Region III (Radian)	2
EPA Region IV	2
EPA Region V (Radian)	20
EPA Region X	2
EPA Region VII	1
OAQPS/EPA (In-house)	1
(Radian)	5
California Air Resources Board (CARB)	6
South Carolina Department of Health and Environmental Control (SCDHEC)	2
Hamilton County Air Pollution Control Board (Tennessee)	1
Massachusetts Department of Environmental Quality Engineering (MDEQE)	1
Memphis & Shelby County Health Department	1
Florida Dept. of Environmental Regulation, Bureau of Air Quality Management (FDER)	1
Oregon Department of Agriculture (OSDA)	1
TOTAL	75

Each ash sampling site was assigned a unique episode number and a range of SCC (sample control center) numbers (for example, Episode 2677 and SCC DQ002000-DQ002099). Each ash sample was assigned a unique SCC number. Also, the samples were checked for proper labeling and packaging before they were sent to the Troika laboratories.

Sample, process and shipping information were logged into a process data and sample tracking table stored on computer disk. The data recorded for each site included:

1. feed materials (suspected CDD precursors were noted),
2. feed rate,
3. type and number of samples,
4. sampling location,
5. characteristics of sampling location (e.g., temperature in ash pit), and
6. combustion parameters (firebox temp, % CO, % O_2) obtained from plant instrumentation.

8.5 SUMMARY OF RESULTS

The data base collected for the Tier 4 program consists of two subsets of data: 1) process data and PCDD/PCDF ash results for the ash sampling program, and 2) process data, PCDD/PCDF flue gas data and PCDD/PCDF ash data for the twelve source test sites. Two separate data bases were formed because the source test sites had three samples of each type of ash analyzed and corresponding flue gas PCDD/PCDF results, while for the ash sampling program only one ash sample per site was analyzed. Each data base will be discussed separately in the following sections.

8.5.1 Ash Sampling Program Data base

The ash sampling program data base includes process data and PCDD/PCDF data for each site. Due to the limited access points in most incinerator and emissions control systems, plant instrumentation was used to collect the incinerator and emissions control device operating data. For some sites plant instrumentation was limited and data were not obtained for some parameters.

The operating data collected was determined by the type of ash sampled. For bottom ash, firebox temperature and CO and O_2 at the incinerator outlet were collected. For flyash (settling chambers, economizers, afterburners), and control device ash, the inlet and/or outlet flue gas temperature, particulate loading, O_2, CO, and firebox temperature were collected, if available. Data on the composition of the fuel and the fuel feedrate were also collected.

The sites were coded by type of combustion. A key to the code is shown in Table 8-6. The process data collected for the ash sites are shown in Table 8-7. For the source test sites which are included, an average of the three test runs is reported. The coolest combustion zone temperatures ($\leq$1,000°F) were found in wire reclamation incinerators, drum & barrel reclamation incinerators, spreader stoker boilers, apartment house incinerators and one hospital waste incinerator. The average firebox temperature and range for each category is shown in Table 8-8.

Combustion parameters such as oxygen and carbon monoxide concentrations were recorded as available. Oxygen data ranged from 0.5 to 19% O_2; carbon monoxide data ranged from 0 to 1,190 ppmv.

The flue gas temperature at the point of collection is summarized in Table 8-9. For bottom ash, the firebox temperature or bottom hearth temperature was used. Baghouses, ESP's and multi-cyclones had the coolest ash and afterburners and bottom ash had the hottest ash.

Due to the volume of information and to aid the reader, the PCDD/PCDF ash sampling program data base is summarized by site (Table 8-10) and by type of ash sampled (Table 8-11). Results are reported for the tetra- through octa-chlorinated dioxin and furan homologues as well as the 2378-TCDD and 2378-TCDF isomers. The total PCDD and total PCDF results are the sum of the tetra- through octa-chlorinated homologues. The PCDD/PCDF concentrations are reported in units of nanogram per gram which is equivalent to parts per billion by weight.

In general, baghouse ash from wood-fired boilers, primary and settling chamber ash from wire reclamation incinerators, baghouse ash from secondary copper smelters and ESP ash from municipal solid waste incinerators contained

TABLE 8-6. SITE CODES

Code	Combustion Device Category
ADK and RKD	Rotary Kiln Dryer
AHI	Apartment House Incinerator
BC	Briquet Charcoal Grill
BLB	Black Liquor Boiler
CB	Commercial Boiler
CK	Cement Kiln
CM	Charcoal Manufacturing
CRF	Carbon Regeneration Furnace
DBI and DBR	Drum and Barrel Reclamation Incinerator
HWI	Hazardous Waste Incinerator
ISW	Industrial Solid Waste Incinerator
MET	Secondary Copper Recovery
MSWI	Municipal Solid Waste Incinerator
OB	Open Burn
SLB	Sulfite Liquor Boiler
SSB	Spreader Stoker Boiler
UB	Utility Boiler
WFB	Wood-fired Boiler
WIH	Hospital Waste Incinerator
WRI	Wire Reclamation Incinerator
WS	Woodstove

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TABLE 8-7. SUMMARY OF ASH SAMPLING PROCESS DATA

Combustion Device Category	Radian Site Code	Fuel	Combustion Device Feedrate/Load	Firebox Temp (F)	Type of Control Device	Control Device Gas Stream Characteristics: Inlet Temp (F)	Inlet O2 (%)	Inlet CO (ppmV)	Inlet Particulate Loading (Grains/dscf)	Outlet Temp (F)	Outlet O2 (%)	Outlet CO (ppmV)	Outlet Particulate Loading (Grains/dscf)
Sewage Sludge Incinerator	SSI-A	Sludge/No.2 Oil/Digester gas	4,100 wet lb/hr	1,400 (hearth 3) 127 (hearth 6)	Multiclones/ Wet Scrubber	NR	12	1190	NR	80	NR	NR	NR
	SSI-B	Sludge	3.75 dry tons/hr	102 (hearth 8)	Wet Scrubber	490	NR	NR	NR	100	NR	NR	NR
	SSI-C												
	SSI-D	Sludge	95-9800 wet lb/hr	1200 max	Wet Scrubber	120	10	NR	NR	90	NR	NR	NR
	SSI-F	Sludge/Nat. Gas	Plant 24 MGD	1500 max	Wet Scrubber	623	7-10	NR	NR	NR	NR	NR	NR
	SSI-G	Sludge	3 tons/hr	NR	Wet Scrubber	NR	NR	NR	NR	NR	NR	NR	NR
	SSI-H	Sludge	NR	NR	Wet Scrubber	NR	NR	NR	NR	NR	NR	NR	NR
	SSI-I	Sludge	6 tons/hr	NR	Wet Scrubber	NR	NR	NR	NR	NR	NR	NR	NR
	SSI-J	Fuel oil/sludge	200 lb/hr dry	NR	Wet scrubber	NR	NR	NR	NR	NR	NR	NR	NR
Black Liquor Boiler	BLB-A	Black Liquor	120,000 lb/hr dry solids	600 at economizer	Wet Bottom ESP	600	3-3.5	NR	NR	600	33.5	NR	NR
	BLB-C	Black liquor	300,000 lb/hr st.	NR	ESP	314	12	840	NR	314	12	840	NR
	BLB-D	Black Liquor	Typical for boiler	NR	Dry Bottom ESP/Scrubber	300-350	5	NR	NR	300-350	NR	NR	NR
	BLB-E	Black Liquor	1) 33,000 lb/hr 2) 93,000 lb/hr	NR	ESP	330	~3-4	NR	NR	300	NR	NR	NR
	BLB-F	Black liquor	360000 lb/hr st.	NR	Economizer ash	350-400	2.5-3.5	NR	NR	NR	NR	NR	NR
	BLB-G	Black liquor 33% mc	350 tpd	2200	ESP/wet scrubber	NR	3	50	NR	170	5	NR	0.074
Wire Reclamation Incinerator	WRI-A	Nat gas/wire ins/transformer insul.	~800 lb/hr	1000 Afterburner 1900	Settling Chamber/ Afterburner	1000	NR	NR	NR	1900	3-10	3400-8000	NR
	WRI-B	Proprietary	Proprietary	Proprietary	Baghouse	Proprietary		----	----	----	----	----	----
	WRI-C	Propane/#2 oil/wire insulation	Not operating at sample time	16-1700 afterburner	Settling Chamber/ Afterburner	NR	0.6 LB/HR HCL		NR	NR	NR	NR	NR
	WRI-D	Natural gas	1963 cfh	NR	Settling Chamber/ Afterburner	NR	NR	NR	NR	NR	NR	NR	NR
Secondary Copper Recovery	MET-A	Plastics, metal	100 tons/hr	NR	Baghouse	300	19	1200	NR	NR	NR	NR	NR
	MET-B	Metallurgical coke	200TPD feed input	NR	Baghouse	200-350	NR	NR	NR	200-350	NR	NR	NR
Carbon Regeneration Furnace	CRF-A	Spent carbon/natural gas	63,000 lb/day	Top hearth 800 Bottom hearth 1800	Spray cooler/ baghouse	390	NR	NR	NR	340	14	20	NR
	CRF-B	Natural gas	600 lb/hr sp car	1200 afterburner	Wet Scrubber	1200	0.5	NR	NR	NR	P=3 in H2	NR	NR
	CRF-C	Natural gas	500 lb/hr spent carbon	700	Afterburner	700	7.5	NR	NR	1500	6% opacit	NR	NR
Wood-fired Boiler	WFB-A	Hogged fuel	45,000 lb/hr	1800	Cyclone/baghouse	470	12	0	0.011	450	12	8	0.011
	WFB-B	Hogged Fuel/45-50 % moisture	175,000 lb/hr steam	2300-2600	Clone/Elec. grav bed	404	NR	NR	NR	404	4	12.5% CO2	0.0070
	WFB-C	Hogged Fuel	4 @ ~50,000 lb/hr	NR	Baghouse	450	11	400	0.498	NR	NR	NR	0.0058
	WFB-D	Pulp/#6 fuel oil/polypropylene	20,000 lb/hr steam	960	Scrubber	343	8	NR	NR	150	NR	NR	NR
	WFB-E	Hogged fuel,44% moi	60000 lb/hr	1600-2000	Multiclone	NR	NR	NR	NR	375	6.5	48	NR
	WFB-F	PDB copperbase on wood/33% mois.	16 ton/hr	2200	Multiclone	450	13.5	140	NR	NR	NR	NR	NR
	WFB-G	Hogged fuel, 15% oil/50 % moisture	300000 lb/hr s	2200-2400	Multiclone		8	4-500					0.3
	WFB-H	Hogged fuel 53% mc	10E6 cu ft/yr wood	1200	Multiclone		8	750		357	6.1		0.145

(Continued)

TABLE 8-7. SUMMARY OF ASH SAMPLING PROCESS DATA (Continued)

Combustion Device Category	Radian Site Code	Fuel	Combustion Device Feedrate/Load	Firebox Temp (F)	Type of Control Device	Control Device Gas Stream Characteristics: Inlet				Outlet			
						Temp (F)	O2 (%)	CO (ppmV)	Particulate Loading (Grains/dscf)	Temp (F)	O2 (%)	CO (ppmV)	Particulate Loading (Grains/dscf)
Drum and Barrel Reclamation Incinerator	DBI-A	Natural Gas	150 drums/hr	1100	None	NR	NM	NM	NR	NR	NR	NM	NR
	DBR-A	Natural Gas	125 drums/hr	1000	Afterburner	NR	NM	NM	NR	NR	NR	NR	NR
	DBI-C	Natural Gas	7.8 mmBtu/hr nat.gas 180 drums&lids/hr	Primary 1200 Afterburner 1350	Afterburner	1500	NR	NR	NR	NR	NR	NR	NR
	DBI-D	Natural Gas	500 drums/hr	1) 950, 2) 1496 Afterburner 1604	Afterburner	NM	NM	NM	NM	NM	NM	NM	NM
	DBI-E	Natural Gas	250 drums/hr	Primary 1500-1700	Afterburner	1500	NR	NR	NR	NR	NR	NR	NR
Hazardous Waste Incinerator	HWI-A	Solvents/plastics/paints	56 x 106 Btu/hr	2000	ESP/Wet Scrubber	1400-1450	10	NM	NM	90	NM	NM	0.06
	HWI-B	PCB's	100 lb/min sludge	Kiln 1700 Afterburner 2230	Afterburner/ Wet Scrubber	outlet inc 180	9	3	NM	NM	NM	NM	NM
	HWI-C	Plastics/Paints/solvents/#2 diesel	10-12MM Btu/hr	1850-1950	Wet Scrubber	NM	13.5	40	NM	NM	NM	NM	NM
Hospital Waste Incinerator	WIH-A	Hospital trash/carcasses/Nat. gas	150 lb/day batch	1500-2000	None	NR	NM	NM	NR	NR	NR	NR	NR
	WIH-B	Lab Animals	0-400 lb/hr	800-900	Dropout Chamber	800-900	NM	NM	NM	NM	NM	NM	NM
	WIH-C	Hospital waste	432 lb/hr		None	NM	NM	NM	NM	NM	NM	NM	NM
	WIH-D	Hospital trash/Nat. gas	550 lb/hr	1600 prim. chamber	None	700/2nd pass of waste heat boiler						11	0.0956
Open Burn	OB-A	Rye grass field	-		None	-----	-----	-----	-----	-----	-----	-----	-----
	OB-B	Trees/Underbrush	-	-	None	-----	-----	-----	-----	-----	-----	-----	-----
Sulfite Liquor Boiler	SLB-A	Spent Sulfite liquor/50% solids	383,000 lbs/hr steam	1930	Absorber/Cooler	450	NM	NM	NM	60-70	15	3.5% CO2	0.0276
	SLB-B	Red Liquor/Coal/Fines/Sawdust	190,000 lb/hr steam		Wet Scrubber	415	2-3	NM	NM	145	NM	NM	NM
	SLB-C	Spent Sulfite liquor/#6 fuel oil	320,000 lb/hr steam	~2500	Wet Scrubber	450	1.5	50-200	NM	150	NM	NM	NM
Woodstove	WS-A	Oak (Runs 1 and 2), Pine (Run 3)	2 kg/hr (avg)		None	-----	-----	-----	-----	-----	17	37,000	-----
	WS-B	Oak/Cedar/Maple	Not measured	Not measured	None	-----	-----	-----	-----	-----	-----	-----	-----
	WS-C	Oak, air dried	Low, air registers closed		None	-----	-----	-----	-----	-----	-----	-----	-----
Spreader Stoker Boiler	SSB-A	Coal	100 x 106 Btu/hr		Multiclones/scrubber	NM	NM	NM	NM	NM	NM	NM	NM
	SSB-B	Coal	64,000 lb/hr steam	600	Multicyclones	430	87ppm	85ppm	NM	310	NM	NM	NM
	SSB-C	Coal	41000 lb/hr		Multiclone	NM	NM	NM	NM	NM	338	11.0	0
Commercial Boiler	CB-A	Phenolic resin dust	19.6 x106 Btu/hr	1500	Multicyclone	500	NM	NM	NM	500	NM	NM	NM
	CB-B	Waste Solvents	10.0MM Btu/hr	1600-1900	Boiler tubes	1600-1900	NM	NM	NM	350-750	NM	NM	NM
Utility Boiler	UB-A	Pulverized Coal	~40 tons/hr	2300	ESP	600 econ.	3	20	NR	NR	NR	NR	NR
	UB-B	Bark/Sawdust/Wood chips	140,000 lb/hr steam	1800	Baghouse	347	6	1000	NM	347	NM	NM	NM
	UB-D	Coal	~55 ton/hr	NM	ESP	240	4.6	5	NM	240	NM	NM	NM
Apartment House Incinerator	AHI-A	Household Garbage/natural gas	150 lbs/hr design	~600 F	None	-----	-----	-----	-----	-----	-----	-----	-----
	AHI-B	Household Garbage/natural gas	250 lb/hr	NM	Venturi Scrubber	NM	NM	NM	NM	NM	NM	NM	NM
	AHI-C	Household Garbage/natural gas	250 lb/hr	NM	Venturi Scrubber	NM	NM	NM	NM	NM	NM	NM	NM
	AHI-D	#6 fuel oil	26 gal/hr seasonal operation		None	-----	-----	-----	-----	-----	-----	-----	-----

TABLE 8-7. SUMMARY OF ASH SAMPLING PROCESS DATA (Continued)

Combustion Device Category	Radian Site Code	Fuel	Combustion Device Feedrate/Load	Firebox Temp (F)	Type of Control Device	Control Device Gas Stream Characteristics Inlet Temp (F)	Inlet O2 (%)	Inlet CO (ppmV)	Inlet Particulate Loading (Grains/dscf)	Outlet Temp (F)	Outlet O2 (%)	Outlet CO (ppmV)	Outlet Particulate Loading (Grains/dscf)
Charcoal Manufacturing	CH-A	Sawdust/fine wood chips	6-7 tons/hr		Afterburner	2100	NR	NR	NR	NR	NR	NR	NR
	CH-B	Wood	95 wet tons	Not available	None	-----	-----	-----	-----	-----	NM	NM	NM
Cement Kiln	CK-A	Coal	150TPH feed	2400-2600	ESP	340	2	NM	NM	NM	NM	NM	NM
	CK-B	Coal	47TPH	2700	ESP	1609	1	NM	NM	NM	NM	NM	NM
Municipal Solid Waste Incinerator	MWI-A	Refuse	375 ton/day	~1600	ESP	550-600	15	300					
	MWI-B	Refuse	5.4 ton/hr	2000 max	Wet Scrubber	1600	110	9% CO2	NM	NM	NM	NM	NM
	MWI-C	Refuse	12.5 ton/hr	NM	Quench/ ESP	1800	131 opac	NM	NM	300	NM	NM	NM
	MWI-D	Municipal solid waste/coal	~300 ton/day	NM	ESP	NM	NM	315	NM	NM	NM	NM	NM
Briquet Charcoal Grill	BC-A	Briquet Charcoal	NR	NR	None	------	------	------	------	------	------	------	------
Industrial Solid Waste Incinerator	IW-A	Wood/paper/paint sludge/plastic	2387 lb/hr	1300	NR	NR	NR	NR	NR	NR	NR	NR	NR
Rotary Kiln Dryer	RKD-A	Recycled fuel oil/ore	120 tons/hr ore	600-800	Baghouse	220	20.5	NM	NM	125	NM	NM	0.008

NR = Data not required.
NM = Plant instrumentation was not available.

TABLE 8-8. AVERAGE COMBUSTION ZONE TEMPERATURES FOR THE COMBUSTION DEVICE CATEGORIES

Combustion Device Category	# Sites	Average Combustion Zone Temperature (°F)
Sewage Sludge Incinerator	9	1400 (1280-1500)
Black Liquor Boiler	7	2200
Wire Reclamation Incinerator	4	1350 (1000-1700)
Secondary Copper Recovery	2	NM
Carbon Regeneration Furnace	3	1200
Wood-Fired Boiler	8	2000 (1200-2500)
Drum & Barrel Reclamation Incinerator	5	1280 (1000-1600)
Hazardous Waste Incinerator	3	1900 (1700-2000)
Hospital Waste Incinerator	4	1400 (800-1700)
Sulfite Liquor Boiler	3	2200 (1950-2500)
Spreader Stoker Boiler	3	600
Commercial Boiler	2	1600 (1500-1750)
Utility Boiler	3	2150 (1800-2500)
Apartment House Incinerator	4	600
Charcoal Manufacturing	2	NM
Cement Kiln	2	2600 (2500-2700)
Municipal Solid Waste Incinerator	4	1800 (1600-2000)
Industrial Solid Waste Incinerator	1	1340
Briquet Charcoal Grill	1	NM
Open Burn	2	NM
Woodstoves	3	NM

NM = Not Monitored

Table 8-9. AVERAGE TEMPERATURE IN THE CONTROL DEVICES AT THE ASH SAMPLING POINT

Sampling Point	# of Sites[a]	Gas Stream Temperature (^oF)
Wet Scrubber	12	inlet: 620 (120-1800) outlet: 120 (65-150)
Multi-Cyclone	8	460 (430-500)
Baghouse	6	360 (300-450)
ESP	9	350 (240-575) 1 ESP at 1600
Settling Chambers	4	900 (850-1000)
Afterburners	3	1700 (1500-2100)
Economizers	5	600 (375-750)
Bottom ash	26	1100 (102-2000)

[a] Includes sites for which temperature data at the ash sampling point were available. Data were not available for all sites.

TABLE 8-10. SUMMARY OF ASH SAMPLING RESULTS

Radian Site Code	Sample Type (Solid/Slurry)		Dioxin Isomer Concentration ng/g (ppb)$^{a\ b}$ 2,3,7,8 TCDD	Other TCDD	PCDD	HXCDD	HPCDD	OCDD	TOTAL PCDD	Furan Isomer Concentrations ng/g (ppb)$^{a\ b}$ 2,3,7,8 TCDF	Other TCDF	PCDF	HXCDF	HPCDF	OCDF	TOTAL PCDF
AHE-A	Bottom Ash		[0.08]	0.50	[0.6]	[0.3]	[0.2]	0.20	0.70	0.10	3.00	2.60	1.20	0.30	[0.06]	7.20
AHE-B	Bottom Ash		[0.007]	0.10	0.10	0.30	0.50	0.50	1.50	0.05	0.75	0.30	0.20	0.10	0.08	1.48
AHE-C	Bottom Ash		[0.02]	[0.03]	[0.07]	[0.02]	0.03	0.02	0.05		0.14	0.07	0.04	[0.02]	[0.02]	0.25
AHE-D	Bottom Ash		[0.01]	[0.07]	[0.04]	[0.04]	[0.04]	0.06	0.06	[0.01]	[0.02]	[0.04]	[0.04]	0.08	0.06	0.08
BC-A	Uncombusted charcoal		[0.005]	[0.01]	[0.01]	0.30	1.30	7.00	8.60		0.02	[0.01]	[[0.05]	0.30	0.30	0.62
BC-A	Bottom Ash		[0.005]	[0.01]	[0.01]	[0.01]	[0.04]	[0.02]	0.00	[0.02]	[0.04]	[0.04]	[0.04]	[0.05]	[0.02]	0.00
BLD-A	Economizer Ash		[0.005]	[0.01]	[0.01]	[[0.02]	[0.01]	0.01	0.01	[0.01]	[0.02]	[0.01]	0.01	[0.01]	[0.01]	0.01
BLD-C	ESP Ash			[0.01]	[0.01]	[0.01]	[0.02]	[0.03]	0.00		[0.04]	[0.01]	[0.03]	[0.02]	[0.01]	0.00
BLD-D	ESP Ash		[0.002]	[0.003]	[0.007]	[0.01]	[0.009]	0.01	0.01	[0.004]	[0.007]	[0.006]	[0.01]	[0.01]	[0.004]	0.00
BLD-E	ESP Ash		[0.009]	[0.009]	[0.007]	[0.01]	[0.01]	[0.008]	0.00	[0.02]	[0.04]	[0.008]	[0.02]	[0.008]	[0.004]	0.00
BLD-F	Economizer Ash			[0.02]	[0.01]	[0.01]	[0.009]	[0.008]	0.00		[0.03]	[0.007]	[0.03]	[0.01]	[0.005]	0.00
BLD-G	ESP Ash		[0.01]	[0.02]	[0.02]	[0.01]	[0.01]	0.01	0.01		0.01	[0.03]	[0.02]	[0.01]	[0.08]	0.01
CD-A	Multi-Clone Ash		[0.006]	[0.009]	[0.006]	[0.007]	[0.006]	0.02	0.02	[0.006]	[0.005]	[0.005]	[0.006]	[0.01]	[0.01]	0.00
CD-B	Fly Ash		[0.03]	0.30	0.60	3.20	6.90	5.90	16.90	0.20	3.50	5.90	7.80	11.60	3.30	32.30
CK-A	ESP Ash		[0.003]	[0.003]	[0.01]	[0.02]	[0.02]	0.13	0.13		0.06	[0.03]	[0.02]	[0.02]	[0.01]	0.06
CK-B	ESP Ash		[0.006]	[0.01]	[0.01]	[0.02]	[0.02]	[0.01]	0.00		0.02	[0.01]	[0.03]	[0.01]	[0.01]	0.02
CM-A	Boiler Fly Ash		[0.003]	0.20	0.05	0.06	0.03	0.03	0.37	0.02	0.18	0.02	0.02	[0.02]	0.01	0.25
CM-A	Afterburner Ash		[0.006]	[0.01]	[0.01]	[0.02]	[0.04]	0.03	0.03	[0.01]	[0.02]	[0.009]	[0.01]	[0.01]	[0.006]	0.00
CM-B	Bottom Ash		[0.01]	[0.03]	[0.02]	[0.04]	[0.03]	0.07	0.07	[0.02]	[0.04]	[0.02]	[0.01]	[0.02]	[0.01]	0.00
CRF-A	Baghouse Ash		[0.01]	0.10	0.20	0.40	0.30	0.10	1.10	[0.03]	0.30	0.10	0.05	[0.05]	0.03	0.48
CRF-B	Filterable solids		[0.001]	0.10	[0.04]	[0.02]	[0.04]	0.02	0.12	[0.02]	0.02	[0.02]	[0.02]	[0.02]	[0.02]	0.02
CRF-C	Afterburner ash		0.10	[34.7]	31.30	29.90	20.30	7.50	89.10	0.20	17.70	10.20	9.60	7.00	0.40	45.10
DBI-A	Bottom Ash			0.02		0.30			0.32		0.03		0.20			0.23
DBR-A	Bottom Ash	Furnace inlet	[0.03]	0.15	[0.6]	0.50	1.90	13.60	16.15	0.20	5.20	3.70	2.90	2.80	1.00	15.80
DBR-A	Bottom Ash	Furnace outlet		0.80				0.37	1.17		10.20				0.31	10.51
DBI-C	Bottom Ash		0.01	0.20	0.20	0.30	0.50	0.80	2.01	0.20	1.40	0.90	0.50	0.40	0.10	3.50
DBI-D	Bottom Ash		[0.02]	[0.03]	[0.2]	[0.3]	0.40	1.30	1.70	[0.05]	[0.1]	[1.2]	0.50	0.50	0.40	1.40
DBI-E	Bottom Ash		0.03	0.17	0.30	2.10	18.00	121.40	142.00	[0.03]	[0.3]	0.10	[0.5]	1.60	1.60	3.30
HWI-A	Bottom Ash		[0.005]	[0.01]	[0.009]	[0.006]	[0.01]	[0.01]	0.00	[0.003]	[0.006]	[0.01]	[0.01]	[0.009]	[0.004]	0.00
HWI-B	Scrubber Water	Analyzed by Dow^c	0.81	8.88		11.60	10.10	8.50	39.90	420.00						420.00
HWI-C	Scrubber Water	Analyzed by Dow^c	[0.08]	[0.2]		0.32	0.94	1.40	2.66	0.28						0.28
ISWI-A	Bottom ash		0.14	1.20	2.60	13.20	56.90	66.70	140.74	[0.02]	0.58	0.41	1.10	3.20	2.20	7.49
MET-A	Baghouse Ash		0.15	2.00	5.00	16.00	36.00	47.00	106.15	8.80	74.50	75.50	96.50	124.50	183.00	562.80
MET-B	Baghouse Ash		[0.3]	77.80	171.40	329.70	411.20	202.70	1192.80	1.70	113.50	150.30	166.60	173.20	28.40	633.70

(Continued)

TABLE 8-10. SUMMARY OF ASH SAMPLING RESULTS (Continued)

Radian Site Code	Sample Type (Solid/Slurry)		Dioxin Isomer Concentration ng/g (ppb) 2,3,7,8 TCDD	Other TCDD	PCDD	HxCDD	HpCDD	OCDD	TOTAL PCDD	Furan Isomer Concentrations ng/g (ppb) 2,3,7,8 TCDF	Other TCDF	PCDF	HxCDF	HpCDF	OCDF	TOTAL PCDF
MWI-B	Scrubber Water	Analyzed by Dow^c	0.80	30.03		24.50	14.90	11.00	81.23	20.00						20.00
MWI-B	Bottom Ash		0.01	0.19	0.20	0.50	0.40	0.20	1.50	0.09	3.11	1.80	1.40	1.00	0.20	7.60
MWI-B	Filterable solids		0.20	2.20	1.40	3.50	5.10	3.10	15.50	1.20	23.50	17.90	13.70	5.60	0.70	62.60
MWI-C	Scrubber water	Analyzed by Dow^c	0.01	0.21		0.82	0.79	0.46	2.29	0.09						0.09
MWI-C	ESP Ash		0.70	22.40	189.00	760.70	1012.10	418.30	2403.20	2.40	70.10	134.80	160.60	163.20	26.20	557.30
MWI-D	ESP Ash		1.20	42.80	45.80	123.00	128.90	61.80	403.50	5.60	163.30	119.90	166.20	114.20	15.40	584.60
CD-A	Ash		[0.04]	[0.08]	[0.1]	[0.08]	[0.1]	0.07	0.07	[0.03]	[0.06]	[0.05]	[0.05]	[0.1]	[0.02]	0.00
CD-B	Ash		[0.04]	[0.07]	[0.01]	[0.02]	[0.01]	0.02	0.02	[0.01]	[0.02]	[0.01]	[0.02]	[0.04]	[0.008]	0.00
RKD-A	Baghouse Ash		[0.01]	[0.02]	[0.02]	[0.02]	[0.01]	[0.008]	0.00		0.20	0.10	0.05	[0.008]	[0.01]	0.35
SLB-A	Filterable solids^d		[0.03]	0.40	[0.4]	[0.4]	0.90	2.30	3.60	[0.1]	0.30	[0.5]	0.30	0.10	[0.1]	0.70
SLB-B	Filterable solids^d		[0.1]	[0.1]	[0.1]	[0.09]	[0.1]	0.10	0.10	[0.005]	[0.01]	[0.1]	[0.1]	[0.09]	[0.06]	0.00
SLB-B	Scrubber Water	Analyzed by Dow^c	[0.008]	[0.015]			[0.02]	[0.012]	0.00	[0.02]	[0.036]					0.00
SLB-C	Filterable solids^d		[0.07]	[0.13]	[0.11]	[0.05]	0.20	0.20	0.40	[0.120]	[0.24]	[0.15]	[0.13]	[0.1]	[0.2]	0.00
SSB-A	Multi-Clone Ash		[0.005]	[0.01]	[0.02]	[0.03]	0.09	0.07	0.16		[0.05]	[0.04]	[0.03]	0.04	0.02	0.06
SSB-B	Multi-Clone Ash		[0.01]	[0.03]	[0.01]	[0.02]	[0.01]	[0.01]	0.00	[0.03]	[0.06]	[0.03]	[0.06]	[0.01]	[0.01]	0.00
SSB-C	Bottom Ash		[0.02]	[0.03]	[0.02]	[0.01]	[0.006]	0.01	0.01	[0.01]	[0.02]	[0.02]	[0.01]	[0.004]	[0.01]	0.00
SSB-C	Multi-clone ash		[0.005]	[0.01]	[0.01]	[0.01]	[0.01]	0.01	0.01		[0.02]	[0.02]	[0.01]	[0.01]	[0.02]	0.00
SSI-A	Bottom Ash		[0.998]	[0.003]	[0.007]	[0.029]	[0.017]	[0.020]	0.00		[0.004]	[0.007]	[0.023]	[0.017]	[0.02]	0.00
SSI-B	Bottom Ash		[0.003]	0.08	0.03	0.08	0.11	0.13	0.43	0.32	1.40	0.70	0.48	0.13	0.03	3.06
SSI-C	Bottom ash			[0.01]	[0.01]	[0.009]	[0.02]	0.02	0.02		[0.07]	[0.02]	[0.03]	[0.02]	[0.01]	0.00
SSI-C	Filterable solids		[0.03]	3.20	[0.4]	3.00	2.30	2.00	10.50	22.20	82.30	56.50	15.50	1.60	0.20	178.30
SSI-C	Filtrate			[0.0001]	[0.001]	[0.0001]	[0.0002]	[0.0001]	0.00		0.00	0.00	0.00	0.00	[0.0001]	0.01
SSI-D	Scrubber Water	Analyzed by Dow^c	[0.12]	[0.17]		[0.25]	0.66	1.80	2.46	[0.13]						0.00
SSI-F	Filterable solids^d		0.20	4.80	3.00	1.10	2.00	2.30	13.40	2.70	88.90	25.30	7.80	2.10	0.30	127.10
SSI-G	Bottom Ash		[0.008]	[0.008]	[0.01]	[0.02]	[0.02]	0.01	0.01	[0.02]	[0.04]	[0.01]	0.02	0.03	0.01	0.06
SSI-H	Bottom Ash		[0.007]	[0.007]	[0.01]	[0.01]	[0.01]	0.01	0.01	[0.005]	0.01	0.01	[0.03]	0.01	[0.008]	0.03
SSI-I	Bottom Ash		[0.04]	[0.08]	[0.02]	[0.02]	[0.02]	0.03	0.03	[0.02]	[0.04]	[0.01]	[0.04]	[0.03]	[0.01]	0.00
SSI-J	Filterable solids		[0.005]	[0.01]	[0.01]	[0.03]	[0.04]	0.02	0.02	[0.02]	[0.04]	[0.02]	0.04	[0.09]	0.03	0.07
UB-A	Economizer Ash		[0.006]	[0.01]	[0.01]	[0.01]	[0.03]	0.02	0.02	[0.01]	[0.02]	[0.01]	0.02	0.20	[0.02]	0.22
UB-B	Baghouse Ash		[0.01]	[0.01]	[0.01]	[0.05]	[0.04]	0.07	0.07		[0.02]	[0.01]	[0.03]	[0.01]	[0.01]	0.00
UB-D	ESP Ash		[0.008]	[0.008]	[0.01]	[0.01]	[0.01]	0.01	0.01	[0.005]	[0.01]	[0.01]	[0.01]	0.01	[0.004]	0.01

(Continued)

TABLE 8-10. SUMMARY OF ASH SAMPLING RESULTS (Continued)

Radian Site Code	Sample Type (Solid/Slurry)		Dioxin Isomer Concentration ng/g (ppb)							Furan Isomer Concentrations ng/g (ppb)						
			2,3,7,8 TCDD	Other TCDD	PCDD	HXCDD	HPCDD	OCDD	TOTAL PCDD	2,3,7,8 TCDF	Other TCDF	PCDF	HXCDF	HPCDF	OCDF	TOTAL PCDF
WFB-A	Baghouse Ash		1.00	228.00	266.20	339.70	306.80	55.50	1197.20	5.60	137.40	66.60	43.97	29.60	2.50	285.67
WFB-A	Bottom Ash	Primary chamber		[0.04]	[0.03]	[0.03]	[0.4]	0.02	0.02		[0.06]	[0.02]	[0.02]	[0.02]	[0.01]	0.00
WFB-A	Bottom Ash	Secondary Chamber	[0.01]	[0.03]	[0.03]	[0.11]	[0.1]	0.08	0.08	[0.01]	[0.04]	[0.02]	[0.03]	[0.02]	[0.02]	0.00
WFB-B	Baghouse Ash			50.70	96.40	41.50	15.80	1.80	206.20		10.40	9.00	2.60	0.50	[0.07]	22.50
WFB-C	Baghouse Ash		[0.01]	179.90	232.60	417.70	128.20	14.60	973.00	0.20	11.40	1.70	0.90	0.60	0.10	14.90
WFB-D	Scrubber Water	Analyzed by Dow	[0.17]	0.86		1.51	1.00	2.10	5.47	0.21						0.21
WFB-E	Multi-clone Ash		[0.01]	[0.02]	[0.03]	[0.01]	[0.02]	0.08	0.08	[0.03]	[0.06]	[0.03]	[0.01]	[0.001]	[0.006]	0.00
WFB-F	Multi-clone Ash		[0.02]	[0.04]	[0.04]	[0.05]	[0.05]	0.06	0.06		0.12	[0.04]	[0.03]	[0.04]	[0.02]	0.12
WFB-G	Multi-clone Ash		[0.02]	[0.03]	[0.02]	[0.02]	[0.03]	[0.05]	0.00	[0.02]	[0.04]	[0.06]	[0.02]	[0.04]	[0.009]	0.00
WFB-H	Multi-clone Ash		[0.2]	[0.06]	[0.06]	[0.06]	[0.04]	[0.06]	0.00	[0.1]	[0.20]	[0.06]	[0.07]	[0.02]	[0.01]	0.00
WDI-A	Bottom Ash		0.01	0.29	0.30	0.50	0.60	0.20	1.90	0.06	2.34	1.70	1.90	1.20	0.20	7.40
WDI-B	Fly Ash		0.04	3.36	0.90	0.50	0.10	0.08	4.98	0.20	3.80	0.60	0.30	[0.08]	[0.01]	4.90
WDI-C	Bottom Ash		[0.01]	[0.02]	[0.02]	0.03	0.02	[0.01]	0.05	[0.015]	0.03	[0.01]	0.02	0.02	[0.01]	0.07
WDI-D	Flyash		0.02	0.10	0.20	2.10	22.30	110.40	135.12	0.20	0.80	3.70	18.80	133.20	217.00	373.70
WDI-D	Primary Ash		0.01	0.10	0.10	0.40	1.50	1.90	4.01	0.05	1.15	2.40	3.70	6.70	3.50	17.50
WRI-A	Bottom ash	1 chamber/Runs 3,4,5	1.70	0.98	1.50	3.40	5.00	3.00	15.53	0.33	4.80	9.30	14.00	17.50	3.90	49.83
WRI-A	Bottom ash	2 chamber/Runs 1,2,6	1.00	3.70	19.30	178.10	478.20	582.40	1262.70	48.00	115.20	486.20	1277.50	1858.80	1859.30	5645.00
WRI-A	Bottom ash	2 chamber/Runs 3,4,5	0.29	2.20	7.00	37.50	67.90	72.70	187.59	6.30	60.20	122.30	232.50	226.00	295.50	882.80
WRI-A	Bottom ash	1 chamber/Runs 1,2,6	0.20	8.30	19.40	61.60	101.10	88.80	279.40	10.50	107.20	157.10	233.90	270.10	161.40	940.20
WRI-B	Baghouse Ash		[0.01]	0.10	0.30	1.30	1.90	1.40	5.00	[0.03]	0.20	0.40	0.90	2.10	1.20	4.80
WRI-C	Settling Chamber Ash		21.70	98.00	211.70	176.70	2540.00	590.10	3433.20	253.20	2202.10	4548.90	2914.30	6451.30	2728.10	19097.90
WRI-D	Fly Ash Before	Afterburner	[0.004]	0.09	[0.07]	0.10	0.20	0.07	0.46	[0.01]	0.30	0.3	0.2	0.2	0.04	0.30
WS-A	Bottom Ash		[0.01]	[0.03]	[0.02]	[0.03]	[0.03]	0.04	0.04	[0.02]	[0.05]	[0.02]	[0.02]	[0.04]	[0.01]	0.00
WS-B	Bottom Ash		[0.005]	[0.01]	[0.008]	[0.009]	[0.01]	[0.01]	0.00	[0.005]	[0.009]	[0.01]	[0.005]	[0.01]	[0.009]	0.00
WS-C	Bottom Ash		[0.006]	[0.01]	[0.01]	[0.01]	[0.006]	0.01	0.01	[0.006]	[0.01]	[0.01]	[0.01]	[0.003]	[0.002]	0.00

a Total = The sum of the tetra- thru octa- chlorinated homologues.
b Results in brackets are minimum detection limits for congeners that were not detected.
c Results reported by Dow under the Region V program included only the tetra, hexa, hepta, and octa-CDDs and 2378 TCDF.
Results are reported on a solids basis.
d Results reported for this sample are in nanograms, not ng/g.

TABLE 8-11. SUMMARY OF ASH SAMPLING RESULTS SORTED BY TYPE OF ASH[a,b]

Radian Site Code	Sample Type (Solid/Slurry)		Dioxin Isomer Concentration ng/g (ppb)							Furan Isomer Concentrations ng/g (ppb)						
			2,3,7,8 TCDD	Other TCDD	PCDD	HXCDD	HPCDD	OCDD	TOTAL PCDD	2,3,7,8 TCDF	Other TCDF	PCDF	HXCDF	HPCDF	OCDF	TOTAL PCDF
CH-A	Afterburner Ash		(0.006)	(0.01)	(0.01)	(0.02)	(0.04)	0.03	0.03	(0.01)	(0.02)	(0.009)	(0.01)	(0.01)	(0.006)	0.00
CRF-C	Afterburner ash		0.10	[34.7]	31.30	29.90	20.30	7.50	89.10	0.20	17.70	10.20	9.60	7.00	0.40	45.10
CRF-A	Baghouse Ash		(0.01)	0.10	0.20	0.40	0.30	0.10	1.10	(0.03)	0.30	0.10	0.05	(0.06)	0.03	0.48
MET-A	Baghouse Ash		0.15	2.00	5.00	16.00	36.00	47.00	106.15	8.80	74.50	75.50	96.50	124.50	183.00	562.80
MET-B	Baghouse Ash		(0.3)	77.80	171.40	329.70	411.20	202.70	1192.80	1.70	113.50	150.30	166.60	173.20	28.40	633.70
RKO-A	Baghouse Ash		(0.01)	(0.02)	(0.02)	(0.02)	(0.01)	(0.008)	0.00		0.20	0.10	0.05	(0.008)	(0.01)	0.35
LD-B	Baghouse Ash		(0.01)	(0.01)	(0.01)	(0.05)	(0.04)	0.07	0.07		(0.02)	(0.01)	(0.03)	(0.01)	(0.01)	0.00
WFB-A	Baghouse Ash		1.00	228.00	206.20	339.70	306.80	96.50	1197.20	5.60	137.40	66.60	43.97	29.00	2.50	285.67
WFB-B	Baghouse Ash			50.70	96.40	41.50	15.80	1.80	206.20		10.40	9.00	2.60	0.50	(0.07)	22.50
WFB-C	Baghouse Ash		(0.01)	179.90	232.60	417.70	128.20	14.00	973.00	0.20	11.40	1.70	0.90	0.60	0.10	14.90
WRI-B	Baghouse Ash		(0.01)	0.10	0.30	1.30	1.90	1.40	5.00	(0.03)	0.20	0.40	0.90	2.10	1.20	4.80
AKI-A	Bottom Ash		(0.03)	0.50	(0.6)	(0.3)	(0.2)	0.20	0.70	0.10	3.00	2.60	1.20	0.30	(0.06)	7.20
AKI-B	Bottom Ash		(0.007)	0.10	0.10	0.30	0.50	0.50	1.50	0.05	0.75	0.30	0.20	0.10	0.08	1.48
AKI-C	Bottom Ash		(0.02)	(0.03)	(0.02)	(0.02)	0.03	0.02	0.05		0.14	0.07	0.04	(0.02)	(0.02)	0.25
AKI-D	Bottom Ash		(0.01)	(0.02)	(0.04)	(0.04)	(0.04)	0.05	0.05	(0.01)	(0.02)	(0.04)	(0.04)	0.03	0.05	0.08
BD-A	Bottom Ash		(0.005)	(0.01)	(0.01)	(0.01)	(0.04)	(0.02)	0.00	(0.02)	(0.04)	(0.04)	(0.04)	(0.05)	(0.02)	0.00
CH-B	Bottom Ash		(0.01)	(0.03)	(0.02)	(0.04)	(0.03)	0.07	0.07	(0.02)	(0.04)	(0.02)	(0.01)	(0.02)	(0.01)	0.00
DBH-A	Bottom Ash			0.02		0.30			0.32		0.03		0.20			0.23
DBH-A	Bottom Ash	Furnace outlet		0.80				0.37	1.17		10.20				0.31	10.51
DBI-B	Bottom Ash	Furnace inlet	(0.03)	0.15	(0.6)	0.50	1.90	13.60	16.15	0.20	5.20	3.70	2.90	2.80	1.00	15.80
DBI-C	Bottom Ash		0.01	0.20	0.20	0.30	0.50	0.80	2.01	0.20	1.40	0.90	0.50	0.40	0.10	3.50
DBI-D	Bottom Ash		(0.02)	(0.03)	(0.2)	(0.3)	0.40	1.30	1.70	(0.05)	(0.1)	(1.2)	0.50	0.50	0.40	1.40
DBI-E	Bottom Ash		0.08	0.17	0.30	2.10	18.00	121.40	142.00	(0.03)	(0.3)	0.10	(0.5)	1.60	1.60	3.30
HWI-A	Bottom Ash		(0.005)	(0.01)	(0.009)	(0.006)	(0.01)	(0.01)	0.00	(0.005)	(0.005)	(0.01)	(0.01)	(0.008)	(0.004)	0.00
ISWI-A	Bottom ash		0.14	1.20	2.60	13.20	56.90	66.70	140.74	(0.02)	0.58	0.41	1.10	3.20	2.20	7.49
MSWI-B	Bottom Ash		0.01	0.19	0.20	0.50	0.40	0.20	1.50	0.09	3.11	1.80	1.40	1.00	0.20	7.60
CD-A	Bottom Ash		(0.04)	(0.08)	(0.1)	(0.08)	(0.1)	0.07	0.07	(0.03)	(0.06)	(0.05)	(0.05)	(0.1)	(0.02)	0.00
CD-B	Bottom Ash		(0.04)	(0.07)	(0.01)	(0.02)	(0.01)	0.02	0.02	(0.01)	(0.02)	(0.01)	(0.02)	(0.04)	(0.008)	0.00
SSB-C	Bottom Ash		(0.02)	(0.03)	(0.02)	(0.01)	(0.006)	0.01	0.01	(0.01)	(0.02)	(0.02)	(0.01)	(0.004)	(0.01)	0.00
SSI-A	Bottom Ash		(0.908)	(0.005)	(0.007)	(0.029)	(0.017)	(0.020)	0.00		(0.004)	(0.007)	(0.023)	(0.017)	(0.02)	0.00
SSI-B	Bottom Ash		(0.008)	0.08	0.03	0.08	0.11	0.13	0.43	0.32	1.40	0.70	0.48	0.13	0.08	3.06
SSI-C	Bottom ash			(0.01)	(0.01)	(0.009)	(0.02)	0.02	0.02		(0.07)	(0.02)	(0.03)	(0.02)	(0.01)	0.00
SSI-G	Bottom Ash		(0.008)	(0.008)	(0.01)	(0.02)	(0.02)	0.01	0.01	(0.02)	(0.04)	(0.01)	0.02	0.03	0.01	0.06
SSI-H	Bottom Ash		(0.007)	(0.007)	(0.01)	(0.01)	(0.01)	0.01	0.01	(0.005)	0.01	0.01	(0.03)	0.01	(0.008)	0.03
SSI-I	Bottom Ash		(0.04)	(0.08)	(0.02)	(0.02)	(0.02)	0.03	0.03	(0.02)	(0.04)	(0.01)	(0.04)	(0.03)	(0.01)	0.00
WFB-A	Bottom Ash	Secondary Chamber	(0.01)	(0.03)	(0.03)	(0.11)	(0.1)	0.08	0.08	(0.01)	(0.04)	(0.02)	(0.03)	(0.02)	(0.02)	0.00
WFB-A	Bottom Ash	Primary chamber		(0.04)	(0.03)	(0.03)	(0.4)	0.02	0.02		(0.06)	(0.02)	(0.02)	(0.02)	(0.01)	0.00
WBH-A	Bottom Ash		0.01	0.29	0.30	0.50	0.60	0.20	1.90	0.06	2.34	1.70	1.90	1.20	0.20	7.40
WBH-C	Bottom Ash		(0.01)	(0.02)	(0.02)	0.03	0.02	(0.01)	0.05	(0.015)	0.03	(0.01)	0.02	0.02	(0.01)	0.07
WBH-D	Bottom Ash	Primary chamber	0.01	0.10	0.10	0.40	1.50	1.90	4.01	0.05	1.15	2.40	3.70	6.70	3.50	17.50
WRI-A	Bottom ash	1 chamber/Runs 3,4,5	1.70	0.93	1.50	3.40	5.00	3.00	15.53	0.33	4.80	9.30	14.00	17.50	3.90	49.80
WRI-A	Bottom ash	2 chamber/Runs 3,4,5	0.29	2.20	7.00	37.50	67.90	72.70	187.59	6.30	60.20	122.30	232.50	226.00	235.50	882.80
WRI-A	Bottom ash	1 chamber/Runs 1,2,6	0.20	8.30	19.40	61.60	101.10	88.80	279.40	10.50	107.20	157.10	233.90	270.10	161.40	940.20
WRI-A	Bottom ash	2 chamber/Runs 1,2,6	1.00	3.70	19.30	178.10	478.20	582.40	1262.70	48.00	115.20	406.20	1277.50	1868.80	1859.30	5645.00
WRI-C	Bottom Ash	Settling chamber	21.70	93.00	211.70	176.70	2340.00	590.10	3433.20	253.20	2202.10	4548.90	2914.30	6451.30	2728.10	19007.90
WS-A	Bottom Ash		(0.01)	(0.03)	(0.02)	(0.03)	(0.03)	0.04	0.04	(0.02)	(0.05)	(0.02)	(0.02)	(0.04)	(0.01)	0.00
WS-B	Bottom Ash		(0.006)	(0.01)	(0.008)	(0.009)	(0.01)	(0.01)	0.00	(0.006)	(0.009)	(0.01)	(0.005)	(0.01)	(0.009)	0.00
WS-C	Bottom Ash		(0.005)	(0.01)	(0.01)	(0.01)	(0.006)	0.01	0.01	(0.005)	(0.01)	(0.01)	(0.01)	(0.008)	(0.002)	0.00
ELB-A	Economizer Ash		(0.006)	(0.01)	(0.01)	([0.02)	(0.01)	0.01	0.01	(0.01)	(0.02)	(0.01)	0.01	(0.01)	(0.01)	0.01

TABLE 8-11. SUMMARY OF ASH SAMPLING RESULTS SORTED BY TYPE OF ASH (Continued)

Radian Site Code	Sample Type (Solid/Slurry)		Dioxin Isomer Concentration ng/g (ppb)							Furan Isomer Concentrations ng/g (ppb)						
			2,3,7,8 TCDD	Other TCDD	PCDD	HXCDD	HPCDD	OCDD	TOTAL PCDD	2,3,7,8 TCDF	Other TCDF	PCDF	HXCDF	HPCDF	OCDF	TOTAL PCDF
ELB-F	Economizer Ash			[0.02]	[0.01]	[0.01]	[0.009]	[0.008]	0.00		[0.03]	[0.007]	[0.03]	[0.01]	[0.005]	0.00
UB-A	Economizer Ash		[0.005]	[0.01]	[0.01]	[0.01]	[0.03]	0.02	0.02	[0.01]	[0.02]	[0.01]	0.02	0.20	[0.02]	0.22
ELB-C	ESP Ash			[0.01]	[0.01]	[0.01]	[0.02]	[0.03]	0.00		[0.04]	[0.01]	[0.03]	[0.02]	[0.01]	0.00
ELB-D	ESP Ash		[0.002]	[0.008]	[0.007]	[0.01]	[0.009]	0.008	0.01	[0.004]	[0.007]	[0.006]	[0.01]	[0.01]	[0.004]	0.00
ELB-E	ESP Ash		[0.009]	[0.009]	[0.007]	[0.01]	[0.01]	[0.008]	0.00	[0.02]	[0.04]	[0.008]	[0.02]	[0.008]	[0.004]	0.00
ELB-G	ESP Ash		[0.01]	[0.02]	[0.02]	[0.01]	[0.01]	0.008	0.01		0.01	[0.03]	[0.02]	[0.01]	[0.08]	0.00
CK-A	ESP Ash		[0.003]	[0.008]	[0.01]	[0.02]	[0.02]	0.13	0.13		0.05	[0.03]	[0.02]	[0.02]	[0.01]	0.05
CK-B	ESP Ash		[0.006]	[0.01]	[0.01]	[0.02]	[0.02]	[0.01]	0.00		0.02	[0.01]	[0.03]	[0.01]	[0.01]	0.02
MSWI-A	ESP Ash			SAMPLE NOT ANALYZED												
MSWI-C	ESP Ash		0.70	22.40	189.00	760.70	1012.10	418.30	2403.20	2.40	70.10	134.00	160.60	163.20	26.20	557.30
MSWI-D	ESP Ash		1.20	42.80	45.80	123.00	128.90	61.80	403.50	5.60	163.30	119.90	166.20	114.20	15.40	584.60
UB-D	ESP Ash		[0.008]	[0.008]	[0.01]	[0.01]	[0.01]	0.01	0.01	[0.006]	[0.01]	[0.01]	[0.01]	0.01	[0.004]	0.01
OFF-B	Filterable solids		[0.001]	0.10	[0.04]	[0.02]	[0.04]	0.02	0.12	[0.02]	0.02	[0.02]	[0.02]	[0.02]	[0.02]	0.02
MSWI-B	Filterable solids		0.20	2.20	1.40	3.50	5.10	3.10	15.50	1.20	23.50	17.90	13.70	5.60	0.70	62.60
SLB-A	Filterable solids[d]		[0.03]	0.40	[0.4]	[0.4]	0.90	2.30	3.60	[0.1]	0.30	[0.5]	0.30	0.10	[0.1]	0.70
SLB-B	Filterable solids[d]		[0.1]	[0.1]	[0.1]	[0.09]	[0.1]	0.10	0.10	[0.006]	[0.01]	[0.1]	[0.1]	[0.09]	[0.06]	0.00
SLB-C	Filterable solids[d]		[0.07]	[0.13]	[0.11]	[0.06]	0.20	0.20	0.40	[0.120]	[0.24]	[0.15]	[0.13]	[0.1]	[0.2]	0.00
SSI-C	Filterable solids		[0.03]	3.20	[0.4]	3.00	2.30	2.00	10.50	22.20	82.30	56.50	15.50	1.60	0.20	178.30
SSI-F	Filterable solids[d]		0.20	4.80	3.00	1.10	2.00	2.30	13.40	2.70	88.90	25.30	7.80	2.10	0.30	127.10
SSI-J	Filterable solids		[0.006]	[0.01]	[0.01]	[0.03]	[0.04]	0.02	0.02	[0.02]	[0.04]	[0.02]	0.04	[0.09]	0.03	0.07
SSI-C	Filtrate			[0.0001]	[0.001]	[0.0001]	[0.0002]	[0.0001]	0.00		0.00	0.00	0.00	0.00	[0.0001]	0.01
CB-B	Flyash		[0.03]	0.30	0.60	3.20	6.90	5.90	16.90	0.20	3.50	5.90	7.80	11.60	3.30	32.30
CH-A	Flyash		[0.008]	0.20	0.05	0.06	0.08	0.08	0.37	0.02	0.18	0.02	0.02	[0.02]	0.01	0.25
WDI-B	Flyash		0.04	3.36	0.90	0.50	0.10	0.08	4.98	0.20	3.80	0.60	0.30	[0.08]	[0.01]	4.90
WDI-D	Flyash		0.02	0.10	0.20	2.10	22.30	110.40	135.12	0.20	0.80	3.70	18.80	133.20	217.00	373.70
WRI-D	Flyash	Before afterburner	[0.004]	0.09	[0.07]	0.1	0.2	0.07	0.46	[0.01]	0.30	0.3	0.2	0.2	0.04	0.30
CB-A	Multi-Clone Ash		[0.006]	[0.009]	[0.006]	[0.007]	[0.006]	0.02	0.02	[0.006]	[0.006]	[0.005]	[0.006]	[0.01]	[0.01]	0.00
SSB-A	Multi-Clone Ash		[0.006]	[0.01]	[0.02]	[0.03]	0.09	0.07	0.16		[0.05]	[0.04]	[0.03]	0.04	0.02	0.06
SSB-B	Multi-Clone Ash		[0.01]	[0.03]	[0.01]	[0.02]	[0.01]	[0.01]	0.00	[0.03]	[0.06]	[0.03]	[0.06]	[0.01]	[0.01]	0.00
SSB-C	Multi-Clone Ash		[0.006]	[0.01]	[0.01]	[0.01]	[0.01]	0.01	0.01		[0.02]	[0.02]	[0.01]	[0.01]	[0.02]	0.00
WFB-E	Multi-Clone Ash		[0.01]	[0.02]	[0.03]	[0.01]	[0.02]	0.08	0.08	[0.03]	[0.06]	[0.03]	[0.01]	[0.001]	[0.006]	0.00
WFB-F	Multi-Clone Ash		[0.02]	[0.04]	[0.04]	[0.06]	[0.05]	0.06	0.06		0.12	[0.04]	[0.03]	[0.04]	[0.02]	0.12
WFB-G	Multi-Clone Ash		[0.02]	[0.03]	[0.02]	[0.02]	[0.03]	[0.05]	0.00	[0.02]	[0.04]	[0.06]	[0.02]	[0.04]	[0.009]	0.00
WFB-H	Multi-Clone Ash		[0.2]	[0.05]	[0.06]	[0.05]	[0.04]	[0.06]	0.00	[0.1]	[0.20]	[0.06]	[0.07]	[0.02]	[0.01]	0.00
HWI-B	Scrubber Water	Analyzed by Dow[c]	0.81	8.89		11.60	10.10	8.50	39.90	420.00						420.00
HWI-C	Scrubber Water	Analyzed by Dow[c]	[0.08]	[0.2]		0.32	0.94	1.40	2.66	0.28						0.56
MSWI-B	Scrubber Water	Analyzed by Dow[c]	0.80	30.03		24.50	14.90	11.00	81.23	20.00						20.00
MSWI-C	Scrubber Water	Analyzed by Dow[c]	0.01	0.21		0.82	0.79	0.46	2.29	0.09						0.09
SLB-B	Scrubber Water	Analyzed by Dow[c]	[0.008]	[0.015]			[0.02]	[0.012]	0.00	[0.02]	[0.036]					0.00
SSI-D	Scrubber Water	Analysed by Dow[c]	[0.12]	[0.17]		[0.25]	0.66	1.80	2.46	[0.13]						0.00
WFB-D	Scrubber Water	Analyzed by Dow[c]	[0.17]	0.86		1.51	1.00	2.10	5.47	0.21						0.21
EC-A	Uncombusted charcoal		[0.005]	[0.01]	[0.01]	0.30	1.30	7.00	8.60		0.02	[0.01]	[[0.05]	0.30	0.30	0.62

a Total = The sum of the tetra- thru octa- chlorinated homologues.

b Results in brackets are minimum detection limits for congeners that were not detected.

c Results reported by Dow under the Region V program included only the tetra, hexa, hepta, and octa-CDDs and 2378 TCDF. Results are reported on a solids basis.

d Results reported for this sample are in nanograms, not ng/g.

higher levels of PCDD/PCDF. PCDD/PCDF concentrations for these source categories ranged from 100 ppb total PCDD or total PCDF to 3400 ppb total PCDD and 19000 ppb total PCDF. It is important to note that these results are for one ash sample collected for each site. Analyses of multiple ash samples from one site are available for the source sites only.

8.5.2 PCDD/PCDF Ash Results for the Source Test Sites

The results of the PCDD/PCDF analyses of the ash samples from the source test sites form a more detailed data base. First, corresponding flue gas data are available. Also, three runs were collected for each type of ash which allowed for the variability of the results to be analyzed.

The average ash and flue gas PCDD/PCDF results are summarized for the source test sites in Table 8-12. Ash samples were not collected at Site BLB-A because particulates at this site was controlled with a wet bottom ESP. At Site BLB-B, a dry bottom ESP was used, but the ash sampling location was inaccessible.

The ash results are summarized by congener for each test run in Table 8-13. The flue gas and incinerator operating results were previously summarized in Table 6-2.

8.6 STATISTICAL ANALYSES OF TIER 4 ASH DATA BASES

The purpose of the statistical analyses was to determine if significant relationships were present in the data. The rationale for selecting the parameters analyzed and the type of statistical analyses used were explained previously in Section 6.0 and are only described briefly here.

Based on previous studies, certain variables have been hypothesized to affect CDD emissions which were listed in Table 6-1. Of these variables, combustion temperature, flue gas temperature at the ash sampling point and the oxygen content of the flue gas were collected for most of the ash sites and used in the analyses.

Non-parametric rank-order statistical analyses were used for the ash data bases because the non-parametric tests require fewer assumptions about the distribution of the population being considered. The ash data base is not well-distributed across all possible values (i.e., order of magnitude or more

TABLE 8-12. COMPARISON OF TIER 4 ASH AND FLUE GAS DATA

Source Category	Site	Ash Sample Type	Average PCDD/PCDF Content Ash (ppt) 2378-TCDD	 Total PCDD	 Total PCDF	 Flue Gas (ng/dscm @ 3% O_2)[a] 2378-TCDD	 Total PCDD	 Total PCDF
Sewage Sludge Incinerators	SSI-A	Bottom Ash	ND	ND	ND	0.05	19.6	34.5
	SSI-C	Bottom Ash	ND	20	70	0.1	52.7	446
		Scrubber water filterable solids (ng/l)	ND	0.7	13			
		Scrubber water filtrate (ppt)	ND	0.3	4.0			
		(ng/l scrubber water)	ND	2×10^{-5}	3×10^{-4}			
	SSI-B	Bottom Ash	ND	10	50	ND	1.6	27.6
Black Liquor[b] Boilers	BLB-C	ESP Ash	ND	20	20	ND	2.9	2.1
Wood Combustion	ISW-A	Bottom Ash	140	138,200	7,400	4.5	625	2390
	WFB-A	Bottom Ash - Primary	NR	150	ND			
		Bottom Ash - Secondary	NR	100	ND			
		Baghouse Dust	100	1,143,600	315,600	0.3	195	83.2
Metals	WRI-A	Bottom Ash - Primary						
		Wire Only	20	240,000	730,000	0.1	173	305
		Wire & Transformer	ND	19,500	82,000	0.1	705	866
		Settling Chamber						
		Wire Only	20	521,000	2,610,300			
		Wire & Transformer	6	231,000	657,600			
	MET-A	Baghouse Dust	150	106,600	571,700	232	11,900	60,700
	DBR-A[c]	Bottom Ash	0.03	17	16	16	688	2,165
Miscellaneous	CRF-A	Baghouse Ash	ND	110	50	ND	3.7	3.3

[a] Flue gas concentration shown for outlet location.

[b] At Site BLB-A, particulates were controlled with wet bottom ESP's, therefore samples were not collected. At Site BLB-B, particulates were controlled with a dry bottom ESP, but the sampling location was inaccessible.

[c] For Site DBR-A, contamination prevented meaningful and valid results.

DBR = Drum and barrel incinerator
SSI = Sewage sludge incinerator
BLB = Black liquor boiler
ISW = Industrial solid waste incinerator
WFB = Wood-fired boiler
WRI = Wire reclamation incinerator
CRF = Carbon regeneration furnace

TABLE 8-13. SUMMARY OF SOURCE TEST SITE ASH RESULTS*

SOURCE	TYPE OF ASH	PCDD CONCENTRATION NG/G (PPB)							PCDF CONCENTRATION NG/G (PPB)						
		2378 TCDD	OTHER TCDD	PENTA-CDD	HEXA-CDD	HEPTA-CDD	OCTA-CDD	TOTAL PCDD	2378 TCDF	OTHER TCDF	PENTA-CDF	HEXA-CDF	HEPTA-CDF	OCTA-CDF	TOTAL PCDF
SSI-A	BOTTOM ASH	[0.002]	[0.002]	[0.005]	[0.034]	[0.016]	[0.016]	ND	NR	[0.003]	[0.005]	[0.034]	[0.016]	[0.016]	ND
SSI-A		[0.003]	[0.003]	[0.009]	[0.025]	[0.016]	[0.022]	ND	NR	[0.005]	[0.008]	[0.019]	[0.016]	[0.022]	ND
SSI-A		[0.003]	[0.003]	[0.006]	[0.024]	[0.020]	[0.022]	ND	NR	[0.004]	[0.006]	[0.017]	[0.020]	[0.022]	ND
SSI-A		[0.003]	[0.003]	[0.007]	[0.028]	[0.017]	[0.020]	ND	NR	[0.004]	[0.006]	[0.028]	[0.017]	[0.020]	ND
ISW-A	BOTTOM ASH	NM	0.07	0.080	0.200	0.500	0.400	1.3	NM	[0.050]	[0.020]	[0.040]	0.040	0.030	0.1
ISW-A		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.0
ISW-A		0.200	1.90	2.700	28.400	126.200	143.200	302.6	[0.030]	1.200	0.900	2.600	7.800	5.200	17.7
ISW-A		0.070	1.63	5.000	10.900	44.100	56.600	118.3	[0.010]	0.900	0.300	0.700	1.900	1.400	4.8
ISW-A		0.140	1.20	2.600	13.200	56.900	66.700	23.5	[0.020]	0.580	0.410	1.100	3.200	2.200	7.5
SSI-B	FILTERABLE SOLIDS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SSI-B	FROM SCRUBBER WATER	0.002	0.05	0.030	0.070	0.140	0.150	0.4	0.090	0.510	0.190	0.160	0.120	0.030	1.1
SSI-B		[0.005]	0.11	0.020	0.080	0.080	0.110	0.4	0.540	2.600	1.200	0.800	0.130	0.020	5.3
SSI-B		0.003	0.08	0.030	0.080	0.110	0.130	0.1	0.320	1.400	0.700	0.480	0.130	0.030	0.5
WRI/W-A	BOTTOM ASH	0.300	7.80	19.900	74.000	155.300	110.900	368.2	9.8	71.9	135.3	246.8	311.0	207.4	982.2
WRI/W-A	(PRIMARY CHAMBER)	0.090	5.81	12.500	33.700	40.000	25.200	117.3	5.9	97.6	97.7	139.5	126.0	36.2	502.9
WRI/W-A		0.200	11.00	25.900	77.000	108.000	130.400	352.5	15.8	152.2	238.4	315.5	373.2	240.5	1335.6
WRI/W-A		0.197	8.20	19.433	61.567	101.100	88.883	279.3	10.5	107.2	157.1	233.9	270.1	161.4	313.4
WRI/W&T-A	BOTTOM ASH	0.020	2.38	4.000	8.400	12.300	7.300	34.4	0.600	13.900	18.400	25.900	30.100	7.100	96.0
WRI/W&T-A	(PRIMARY CHAMBER)	4.900	0.20	0.300	1.200	1.600	1.500	9.7	0.200	0.100	8.000	15.100	20.900	4.100	48.4
WRI/W&T-A		[0.100]	[0.200]	[0.200]	[0.500]	[1.00]	0.200	0.2	[0.200]	[0.400]	[1.40]	1.000	1.400	0.600	3.0
WRI/W&T-A		1.640	0.86	1.433	3.200	4.633	3.000	14.8	0.400	7.000	13.200	14.000	17.467	3.983	49.1
WRI/W-A	BOTTOM ASH	0.600	3.8	18.7	151.6	360.3	507.2	1042.2	44.6	75.4	401.9	1256.4	1895.1	2309.2	5982.6
WRI/W-A	(SETTLING CHAMBER)	0.200	0.6	13.6	79.8	199.0	235.1	528.3	22.4	60.8	282.5	765.3	886.9	652.6	2620.5
WRI/W-A		2.300	6.7	25.7	303.0	875.3	1004.9	2217.9	76.9	209.4	774.8	1810.8	2844.4	2616.1	8832.4
WRI/W-A		1.033	3.70	19.3	178.1	478.2	582.4	1262.8	48.0	115.2	486.4	1277.5	1858.8	1859.3	5645.2
WRI/W&T-A	BOTTOM ASH	0.060	0.54	4.1	34.0	97.9	99.0	235.6	1.8	30.8	77.1	197.5	216.8	157.9	681.9
WRI/W&T-A	(SETTLING CHAMBER)	0.300	3.8	13.6	58.6	65.5	52.4	194.2	6.7	98.3	198.3	282.7	274.1	224.6	1074.7
WRI/W&T-A		0.500	2.4	3.3	19.8	40.4	66.6	133.0	10.5	56.4	96.6	217.4	187.0	328.9	891.8
WRI/W&T-A		0.287	2.25	7.0	37.5	67.9	72.7	187.6	6.3	60.2	122.3	232.5	226.0	295.5	882.8
WFB-A	BOTTOM ASH	NM	[0.060]	[0.030]	[0.030]	[0.400]	0.030	0.0	NM	[0.060]	[0.020]	[0.010]	[0.020]	[0.004]	ND
WFB-A	(PRIMARY CHAMBER)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
WFB-A		NM	[0.020]	[0.020]	[0.020]	[0.010]	0.010	0.0	NM	[0.090]	[0.010]	[0.020]	[0.010]	[0.010]	ND
WFB-A		NM	[0.040]	[0.025]	[0.025]	[0.200]	0.020	0.0	NM	[0.055]	[0.015]	[0.015]	[0.015]	[0.007]	ND
WFB-A	BOTTOM ASH	NM	[0.040]	[0.030]	[0.090]	[0.200]	0.090	0.1	NM	[0.060]	[0.020]	[0.040]	[0.040]	[0.040]	ND
WFB-A	(SECONDARY CHAMBER)	[0.010]	[0.020]	[0.050]	[0.200]	[0.100]	[0.060]	ND	[0.010]	[0.010]	[0.040]	[0.050]	[0.030]	[0.020]	ND
WFB-A		NM	[0.020]	[0.020]	[0.030]	[0.009]	0.100	0.1	NM	[0.040]	[0.010]	[0.010]	[0.004]	[0.001]	ND
WFB-A		[0.010]	[0.030]	[0.033]	[0.100]	[0.100]	0.095	0.1	[0.010]	[0.037]	[0.023]	[0.033]	[0.025]	[0.020]	ND
WFB-A	BAGHOUSE ASH	1.000	215.1	258.8	319.3	410.3	71.7	1276.2	5.700	151.900	70.100	42.400	37.500	3.000	310.6
WFB-A		0.800	258.9	288.4	378.1	252.0	43.7	1221.9	4.500	131.600	64.400	49.000	27.700	2.300	279.5
WFB-A		1.200	210.1	251.4	321.7	258.0	51.0	1098.4	6.500	128.800	65.300	40.500	23.700	2.300	267.1
WFB-A		1.000	228.03	266.2	339.7	306.8	55.5	1197.2	5.567	137.433	66.600	43.967	29.633	2.533	286.7

TABLE 8-13. SUMMARY OF SOURCE TEST SITE ASH RESULTS (Continued)*

SOURCE	TYPE OF ASH	PCDD CONCENTRATION NG/G (PPB)							PCDF CONCENTRATION NG/G (PPB)						
		2378 TCDD	OTHER TCDD	PENTA-CDD	HEXA-CDD	HEPTA-CDD	OCTA-CDD	TOTAL PCDD	2378 TCDF	OTHER TCDF	PENTA-CDF	HEXA-CDF	HEPTA-CDF	OCTA-CDF	TOTAL PCDF
BLB-C	ESP ASH	NM	[0.02]	[0.02]	[0.01]	[0.03]	0.030	0.03	NM	0.040	0.020	0.040	0.020	0.020	0.14
BLB-C		NM	[0.01]	[0.01]	[0.02]	[0.02]	0.020	0.02	NM	0.050	0.010	0.030	0.030	0.010	0.13
BLB-C		NM	[0.01]	[0.01]	[0.01]	[0.01]	[0.03]	ND	NM	0.020	0.008	0.020	0.010	0.010	0.07
BLB-C		NM	[0.01]	[0.01]	[0.01]	[0.02]	0.017	0.02	NM	0.037	0.013	0.030	0.020	0.013	0.11
CRF-A	BAGHOUSE ASH	NR	0.2	0.200	0.400	0.300	0.100	1.2	NR	0.300	0.100	[0.02]	[0.05]	[0.05]	0.40
CRF-A		NR	0.1	0.200	0.400	0.300	0.100	1.1	NR	0.400	0.200	[0.04]	0.040	0.030	0.67
CRF-A		[0.01]	0.1	0.100	0.300	0.300	0.200	1.0	[0.03]	0.300	0.060	0.100	[0.06]	0.020	0.48
CRF-A		[0.01]	0.13	0.167	0.367	0.300	0.133	1.1	[0.03]	0.333	0.120	0.100	0.040	0.025	0.52
MET-A	BAGHOUSE ASH	0.200	3.1	9.500	20.400	47.700	66.800	147.7	10.9	102.8	154.4	156.7	159.0	228.6	812.4
MET-A	(NO. 1)	0.100	2.5	5.100	18.800	46.600	49.800	122.9	9.6	84.0	105.4	139.2	175.0	226.8	740.0
MET-A		0.200	2.7	2.200	23.000	38.600	44.000	110.7	11.8	85.9	28.6	126.4	128.6	166.2	547.5
MET-A		0.167	2.77	5.600	20.733	44.300	53.533	127.1	10.8	90.9	96.1	140.8	154.2	207.2	700.0
MET-A	BAGHOUSE ASH	0.130	1.900	5.000	11.500	36.800	55.400	110.7	6.400	63.100	67.300	40.000	120.000	205.200	502.0
MET-A	(NO. 2)	0.040	1.700	4.500	10.400	27.200	34.400	78.2	4.100	39.900	47.800	52.000	88.800	139.400	372.0
MET-A		0.200	1.800	3.600	12.000	19.000	31.400	68.0	10.100	71.200	49.800	64.800	75.400	131.800	403.1
MET-A		0.123	1.800	4.367	11.300	27.667	40.400	85.7	6.867	58.067	54.967	52.267	94.733	158.800	425.7
DBR-A	BOTTOM ASH	a	0.6	a	a	a	a	a	a	6.400	a	a	a	a	a
DBR-A	(FURNACE OUTLET)	a	1	a	a	a	0.370	a	a	13.900	a	a	a	0.310	a
DBR-A		a	a	a	a	a	a	a	a	a	a	a	a	a	a
DBR-A		a	0.8	a	a	a	0.370	a	a	10.200	a	a	a	0.310	a
DBR-A	BOTTOM ASH	a	0.2	a	a	a	a	a	a	2.600	a	a	a	a	2.6
DBR-A	(FURNACE INLET)	0.030	0.06	[0.600]	0.500	1.200	1.400	a	0.200	8.200	6.400	4.600	4.500	1.300	25.2
DBR-A		NM	0.2	[0.030]	0.500	2.600	25.800	a		2.200	0.900	1.100	1.100	0.600	5.9
DBR-A		0.030	0.15	0.000	0.500	1.900	13.600	a	0.200	6.500	3.650	2.850	2.800	0.950	16.9
SSI-C	FILTERABLE SOLIDS	[0.020]	2.3	[0.200]	2.600	1.800	1.400	8.1	18.900	68.800	45.500	14.900	1.500	0.200	149.8
SSI-C	FROM SCRUBBER WATER	[0.040]	3.2	[0.500]	2.600	2.300	2.300	10.4	20.600	79.400	56.800	12.600	1.500	0.200	171.1
SSI-C		[0.030]	4	[0.400]	3.800	2.800	2.300	12.9	27.200	98.800	67.200	19.000	1.800	0.200	214.2
SSI-C		[0.030]	3.17	[0.400]	3.000	2.300	2.000	10.5	22.233	82.333	56.500	15.500	1.600	0.200	178.4
SSI-C	FILTRATE FROM	NM	[0.0001]	[0.0001]	[0.0001]	0.0002	0.0002	0.0004	NM	[0.0005]	0.0001	0.0001	0.0002	[0.0001]	0.0004
SSI-C	SCRUBBER WATER	NM	0.0001	[0.0001]	0.0002	0.0002	0.0001	0.0006	NM	0.008	0.0020	0.0008	0.0001	[0.0001]	0.0059
SSI-C		NM	0.0001	[0.0001]	[0.0001]	0.0002	0.0001	0.0004	NM	0.008	0.0020	0.0007	0.0001	[0.0001]	0.0058
SSI-C		NM	0.0001	[0.0001]	0.0002	0.0002	0.0001	0.0005	NM	0.008	0.0014	0.0006	0.0001	[0.0001]	0.0040
SSI-C	BOTTOM ASH	NM	[0.020]	[0.010]	[0.010]	[0.020]	0.020	0.02	NM	[0.020]	0.010	0.060	0.030	[0.010]	0.10
SSI-C		NM	[0.010]	[0.010]	[0.007]	[0.010]	0.020	0.02	NM	0.120	[0.030]	[0.020]	[0.004]	[0.020]	0.12
SSI-C		NM	[0.010]	[0.005]	[0.009]	[0.020]	0.020	0.02	NM	[0.070]	[0.010]	[0.020]	[0.020]	[0.006]	0.00
SSI-C		NM	[0.010]	[0.008]	[0.009]	[0.017]	0.020	0.02	NM	0.040	0.010	0.060	0.030	[0.010]	0.07

*Average values for three test runs are shown.

a The analytical results did not satisfy QA requirements. Therefore, meaningful results could not be obtained.

NM = Isomer not quantified due to low concentrations of the tetra, penta, and hexa homologues.

NS = Sample not submitted for analysis.

differences between values from different sites) and for this reason, non-parametric analyses are believed to be more valid.

A statistical software package was used to perform the analyses. The software generates a matrix of correlation coefficients corresponding to all the possible combinations of the parameters to be analyzed.

In evaluating the results, it was assumed that if the coefficient for a possible combination was greater than or equal to 0.85, then a strong association existed between the two parameters. Coefficients between 0.7 and 0.85 indicated a moderate association and coefficients between 0.5 and 0.7 indicated a weak association. Negative coefficients indicated an inverse relationship.

The source test ash data and the ash program data were analyzed separately. The source test ash data were analyzed for flue gas-ash and operating data-ash relationships. The ash program data were analyzed only for operating data-ash relationships. The results of the analyses are discussed in the following sections.

8.6.1 Non-parametric Rank Order Statistical Analysis of the Source Test Ash Data

The PCDD/PCDF data for the flue gas and ash as well as the process data were correlated, first, by not differentiating between the type of ash and secondly, by sorting the data into bottom ash and fly ash.

The first correlation resulted in weak correlations at best ($R < 0.7$). Examination of the data base indicated that bottom ash was a good example of ash for which the PCDD/PCDF in the ash did not correlate with the PCDD/PCDF in the flue gas (i.e., flue gas PCDD/PCDF did not increase as bottom ash PCDD/PCDF increased).

Then, the correlation was performed again, excluding the bottom ash data. The associations were significant for this correlation and are summarized in Table 8-14. The control device ash PCDD/PCDF level was found to be strongly associated with uncontrolled flue gas PCDD/PCDF levels and weakly associated with controlled flue gas PCDD/PCDF levels. Also, the maximum flue gas temperature prior to collection was found to be inversely related to PCDD/PCDF levels in the flue gas and control device ash. It should be noted, however, that these correlations were drawn based on data from five sites in five

TABLE 8-14. EXAMINATION OF ASH/FLUE GAS RANK NON-PARAMETRIC SPEARMAN CORRELATIONS

Assumptions: Bottom ash results not included in database.

Strong Association: $R \geq 0.85$
Moderate Association: $0.7 \leq R < 0.85$
Weak Association: $0.5 \leq \bar{R} < 0.7$

Parameter	Relationship
Maximum flue gas temperature prior to collection by control device	1. Moderate inverse association with uncontrolled flue gas PCDD/PCDF levels. 2. Weak inverse association with controlled flue gas PCDD/PCDF levels. 3. Weak inverse association with control device ash PCDD/PCDF levels.
Combustion Temperature in Firebox	Strong association with uncontrolled flue gas PCDD/PCDF levels
Oxygen level in the flue gas	Moderate association with controlled flue gas PCDD/PCDF levels
Carbon monoxide level in the flue gas	Moderate association with controlled flue gas PCDD/PCDF levels
Control device ash PCDD/PCDF level	1. Strong association with uncontrolled flue gas PCDD/PCDF levels 2. Weak association with controlled flue gas PCDD/PCDF levels

different source categories (SSI-B, WFB-A, BLB-C, CRF-A, and MET-A). The type of ash analyzed included baghouse ash, ESP ash, and filterable solids from scrubber water.

8.6.2 Non-parametric Rank Order Statistical Analysis of the Ash Sampling Program Data

Based on the results of the source test data statistical analyses, the ash sampling program data was first sorted by ash type and then correlated. This step was necessary, since approximately 40 percent of the sites had bottom ash samples analyzed. Multicyclone ash, baghouse ash, ESP ash and filterable solids from scrubber water were the next most prevalent types of ash collected at 10 percent of the sites, each. The remaining 20 percent of the samples were afterburner ash, economizer ash, and fly ash.

The lack of reported operating data limited the sampling parameters to temperature of the flue gas at the sampling location, and firebox temperature. The results of the statistical analysis by type of ash are summarized in Table 8-15. For ashes other than bottom ash, flue gas temperature at the control device was weakly associated with the PCDD/PCDF level in the ash.

8.6.3 Summary of the Ash Sampling Program

The ash sampling program attempted to qualitatively determine the relationship between PCDD/PCDFs in the flue gas and PCDD/PCDFs in ash. Corresponding ash and flue gas data were collected from ten sites which included eight types of incinerators and four types of ash. The data were analyzed using non-parameter rank statistics excluding the bottom ash data. The following conclusions were reached:

1. Control device ash PCDD/PCDF results are a qualitative indicator for the presence of CDD/CDF in the uncontrolled flue gas.

2. Control device ash PCDD/PCDF results are a weaker qualitative indicator for the presence of CDD/CDF in the controlled flue gas than CDD/CDF in uncontrolled flue gas.

TABLE 8-15. EXAMINATION OF ASH SAMPLING PROGRAM RANK
NON-PARAMETRIC SPEARMAN CORRELATIONS
SORTED BY TYPE OF ASH

Assumptions: Sorted by Ash Type.

Strong Association: $R \geq 0.85$
Moderate Association: $0.7 \leq R < 0.85$
Weak Association: $0.5 \leq R < 0.7$

Ash Type	Parameter	Relationship
Bottom Ash	No significant correlations	
Baghouse Ash	Firebox temperature and flue gas temperature at control device	Weak association with PCDD/PCDF levels in the ash
Economizer Ash and Afterburner Ash	Insufficient cases for valid correlation	
ESP Ash	Flue gas temperature at control device	Weak association with 2378-TCDD equivalents in ash
Fly Ash	Firebox temperature and and flue gas temperature at control device	Moderate association with 2378-TCDD equivalents in ash
Filterable Solids from Scrubber Water	1. Inlet temperature to scrubber	Weak association with PCDD/PCDF in ash
	2. Outlet temperature to scrubber	Moderate inverse relationship with PCDD/PCDF in ash
Multicyclone Ash	Flue gas temperature at control device	Weak association with PCDD/PCDF in ash

3. Bottom ash is not a good indicator of PCDD/PCDF in the flue gas because of the inconsistent results observed between sources. Also, one case of false negative results (i.e., not detected in the bottom ash but detected in the flue gas) did occur for Site SSI-A.

4. False negatives and false positive results did not occur for the control device ash (i.e., PCDD/PCDF were always detected in the control device ash when measured in the stack gases.)

5. The maximum temperature achieved in the process stack, conveyor, or firebox prior to collection of the control device ash is inversely related to the PCDD/PCDF levels in the uncontrolled flue gas, controlled flue gas and control device ash.

6. The flue gas temperature at the control device is weakly associated with the PCDD/PCDF levels in control device ash.

8.7 EVALUATION OF RANKING OF SOURCE CATEGORIES

In order to evaluate the original ranking of the source categories as potential emitters of PCDD/PCDF, the ash results were converted to an equivalent basis using 2378-TCDD toxic equivalents. The original ranking was presented previously in Table 8-3.

The 2378-TCDD toxic equivalency factors used were developed by EPA and were previously presented in Table 5-3. The factors rank the toxicity of a congener relative to the toxicity of 2378-TCDD which is given an equivalency of one. The sites are ranked in descending order by 2378-TCDD toxic equivalents in Table 8-16.

Of the 75 sites sampled, 19 of the sites had 2378-TCDD toxic equivalencies above 1 ppb. The sites above 1 ppb were mostly from the B category with two A category sites, one C category site and one D category site. Using these results along with the conclusion that PCDD/PCDF in the control device ash may qualitatively indicate PCDD/PCDF in the flue gas, the

TABLE 8-16. SUMMARY OF ASH SAMPLING PROGRAM RESULTS SORTED BY 2378 TCDD TOXIC EQUIVALENTS[a,b]

Radian Site Code	Tier 4 Original Ranking	Sample Type (Solid/Slurry)		Dioxin Isomer Concentration ng/g (ppb) 2,3,7,8 TCDD	Other TCDD	PCDD	HxCDD	HpCDD	OCDD	TOTAL PCDD	Furan Isomer Concentrations ng/g (ppb) 2,3,7,8 TCDF	Other TCDF	PCDF	HxCDF	HpCDF	OCDF	TOTAL PCDF	2378-TCDD EQUIVALENTS (PPB)
WRI-C	B	Bottom Ash	Settling chamber	21.70	93.00	211.70	176.70	2340.00	390.10	3233.20	233.20	2202.10	4588.90	2914.30	6431.30	2728.10	19097.90	633.9
WFB-A	B	Baghouse Ash		1.00	229.00	266.20	339.70	306.00	55.30	1197.20	5.60	137.40	66.60	43.97	29.60	2.50	285.67	150.1
MSWI-C	B	ESP Ash		0.70	22.40	189.00	760.70	1012.10	618.30	2603.20	2.40	70.10	134.80	160.60	163.20	26.20	557.30	142.4
WFB-C	B	Baghouse Ash		[0.01]	179.90	232.60	417.70	128.20	14.60	973.00	0.20	11.40	1.70	0.90	0.60	0.10	14.90	135.1
MEI-B	B	Baghouse Ash		[0.3]	77.00	171.40	329.70	311.20	302.70	1192.00	1.70	113.30	150.30	166.60	173.20	28.40	633.70	117.2
WRI-A	B	Bottom ash	2 chamber/Runs 1,2,6	1.00	3.70	19.30	178.10	678.20	382.40	1262.70	48.00	115.20	466.20	1277.50	1050.00	1059.30	3645.00	86.3
WFB-B	B	Baghouse Ash			50.70	96.60	41.30	15.80	1.80	206.20		10.40	9.00	2.60	0.50	[0.07]	22.50	51.3
MSWI-B	B	ESP Ash		1.20	82.00	83.00	123.00	128.90	64.80	483.50	5.60	163.30	119.90	166.20	114.20	15.40	584.60	44.1
HMI-B	B	Scrubber Water	Analyzed by Dow[c]	0.01	9.89		11.60	10.10	8.30	39.90	420.00						420.00	42.9
WRI-A	B	Bottom ash	1 chamber/Runs 1,2,6	0.20	0.30	19.40	61.60	101.10	96.80	279.40	10.50	107.20	157.10	233.90	270.10	161.40	940.20	32.0
WRI-A	B	Bottom ash	2 chamber/Runs 3,4,5	0.29	2.20	7.00	37.50	67.90	72.70	187.59	6.30	60.20	122.30	232.50	226.00	235.50	882.80	20.9
CRF-C	B	Afterburner ash		0.10	[34.7]	31.30	29.90	20.30	7.50	89.10	0.20	17.70	10.20	9.60	7.00	0.40	45.10	18.1
MEI-A	B	Baghouse Ash		0.15	2.00	5.00	16.00	36.00	47.00	106.15	8.00	74.50	75.50	96.50	124.50	183.00	562.00	12.9
SSI-C	A	Filterable solids[d]		[0.03]	3.20	[0.4]	3.00	2.30	2.00	10.50	22.20	82.30	56.30	15.50	1.60	0.20	178.30	8.3
SSI-F	A	Filterable solids[d]		0.20	4.80	3.00	1.10	2.00	2.30	13.40	2.70	88.90	25.30	7.80	2.10	0.30	127.10	---
MSWI-B	B	Scrubber Water	Analyzed by Dow[c]	0.80	30.03		24.50	14.90	11.00	81.23	20.00						20.00	4.1
WRI-A	B	Bottom ash	1 chamber/Runs 3,4,5	1.70	0.93	1.50	3.40	5.00	3.00	15.53	0.33	4.80	9.30	14.00	17.50	3.90	49.83	3.7
MSWI-B	B	Filterable solids		0.20	2.20	1.40	3.50	5.10	3.10	15.50	1.20	23.50	17.90	13.70	5.60	0.70	62.60	3.1
ISWI-A	B	Bottom ash		0.14	1.20	2.60	13.20	36.90	46.70	100.74	[0.02]	0.58	0.41	1.10	3.20	2.20	7.49	2.1
CB-B	C	Flyash		[0.03]	0.30	0.60	3.20	6.90	5.90	16.90	0.20	3.50	5.90	7.80	11.60	3.30	32.30	1.1
WIH-D	C	Flyash		0.02	0.10	0.20	2.10	22.30	110.40	135.12	0.20	0.80	3.70	18.80	133.20	217.00	373.70	0.9
WIH-B	C	Flyash		0.04	3.36	0.90	0.30	0.10	0.08	4.98	0.20	3.80	0.60	0.30	[0.08]	[0.01]	4.90	0.6
DBR-A	B	Bottom Ash	Furnace inlet	[0.03]	0.15	[0.6]	0.50	1.90	13.60	16.15	0.20	5.20	3.70	2.90	2.80	1.00	15.80	0.5
WIH-A	C	Bottom Ash		0.01	0.29	0.30	0.50	0.60	0.20	1.90	0.06	2.34	1.70	1.90	1.20	0.20	7.40	0.4
WIH-B	C	Bottom Ash	Primary chamber	0.01	0.10	0.10	0.40	1.50	1.90	4.01	0.05	1.15	2.40	3.70	6.70	3.50	17.50	0.4
MSWI-B	B	Bottom Ash		0.01	0.19	0.20	0.30	0.40	0.20	1.30	0.09	3.11	1.80	1.40	1.00	0.20	7.60	0.3
WRI-B	B	Baghouse Ash		[0.01]	0.10	0.30	1.30	1.90	1.40	5.00	[0.03]	0.20	0.40	0.90	2.10	1.20	4.80	0.3
DBI-E	B	Bottom Ash		0.03	0.17	0.30	2.10	18.00	121.40	142.00	[0.03]	[0.3]	0.10	[0.3]	1.60	1.60	3.30	0.3
AHI-A	C	Bottom Ash		[0.03]	0.50	[0.6]	[0.3]	[0.2]	0.20	0.70	0.10	3.00	2.60	1.20	0.30	[0.06]	7.20	0.3
DBI-C	B	Bottom Ash		0.01	0.20	0.20	0.30	0.50	0.80	2.01	0.20	1.40	0.90	0.50	0.40	0.10	3.50	0.2
CRF-A	B	Baghouse Ash		[0.01]	0.10	0.20	0.40	0.30	0.10	1.10	[0.03]	0.30	0.10	0.05	[0.06]	0.03	0.48	0.1
SSI-B	A	Bottom Ash		[0.003]	0.08	0.03	0.08	0.11	0.13	0.43	0.32	1.40	0.70	0.48	0.13	0.03	3.06	0.1
WFB-B	B	Scrubber Water	Analyzed by Dow[c]	[0.17]	0.86		1.51	1.00	2.10	5.47	0.21						0.21	0.1
AHI-B	C	Bottom Ash		[0.007]	0.10	0.10	0.30	0.50	0.50	1.50	0.05	0.75	0.30	0.20	0.10	0.08	1.48	0.1
MSWI-C	B	Scrubber Water	Analyzed by Dow[c]	0.01	0.21		0.82	0.79	0.46	2.29	0.09						0.09	0.1
WRI-B	B	Flyash	Before afterburner	[0.004]	0.09	[0.07]	0.1	0.2	0.07	0.46	[0.01]	0.30	0.3	0.2	0.2	0.04	0.30	0.0
CH-A	C	Flyash		[0.003]	0.20	0.05	0.06	0.03	0.03	0.37	0.02	0.18	0.02	0.02	[0.02]	0.01	0.25	0.0
DBR-A	B	Bottom Ash	Furnace outlet		0.80				0.37	1.17		10.20				0.31	10.51	0.0
DBI-A	B	Bottom Ash			0.02		0.30			0.32		0.03		0.20			0.23	0.0
BC-A	UN	Uncombusted charcoal		[0.003]	[0.01]	[0.01]	0.30	1.30	7.00	8.60		0.02	[0.01]	[(0.05)]	0.30	0.30	0.62	0.0
HMI-C	C	Scrubber Water	Analyzed by Dow[c]	[0.08]	[0.2]		0.32	0.94	1.40	2.66	0.28						0.56	0.0
SLB-A	C	Filterable solids[d]		[0.03]	0.40	[0.4]	[0.4]	0.90	2.30	3.60	[0.1]	0.30	[0.5]	0.30	0.10	[0.1]	0.70	---
AHI-C	C	Bottom Ash		[0.02]	[0.03]	[0.02]	[0.02]	0.03	0.02	0.05		0.14	0.07	0.04	[0.02]	[0.02]	0.25	0.0
DBI-B	B	Bottom Ash		[0.02]	[0.03]	[0.2]	[0.3]	0.40	1.30	1.70	[0.05]	[0.1]	[1.2]	0.50	0.50	0.40	1.40	0.0
SSI-H	A	Bottom Ash		[0.007]	[0.007]	[0.01]	[0.01]	[0.01]	0.01	0.01	[0.005]	0.01	0.01	[0.03]	0.01	[0.008]	0.03	0.0

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TABLE 8-16. SUMMARY OF ASH SAMPLING PROGRAM RESULTS SORTED BY 2378 TCDD TOXIC EQUIVALENTS (Continued)[a,b]

Radian Site Code	Tier 4 Original Ranking	Sample Type (Solid/Slurry)		Dioxin Isomer Concentration ng/g (ppb) 2,3,7,8 TCDD	Other TCDD	PCDD	HxCDD	H7CDD	OCDD	TOTAL PCDD	Furan Isomer Concentrations ng/g (ppb) 2,3,7,8 TCDF	Other TCDF	PCDF	HxCDF	H7CDF	OCDF	TOTAL PCDF	2378-TCDD EQUIVALENTS (PPB)
CRF-B	B	Filterable solids		[0.001]	0.10	[0.04]	[0.02]	[0.04]	0.02	0.12	[0.02]	0.02	[0.02]	[0.02]	[0.02]	[0.02]	0.02	0.0
WIH-C	C	Bottom Ash		[0.01]	[0.02]	[0.02]	0.03	0.02	[0.01]	0.05	[0.015]	0.03	[0.01]	0.02	0.02	[0.01]	0.07	0.0
SSI-B	A	Scrubber Water	Analyzed by Dow[c]	[0.12]	[0.17]		[0.25]	0.44	1.80	2.44	[0.13]						0.00	0.0
SSI-J	A	Filterable solids		[0.005]	[0.01]	[0.01]	[0.03]	[0.04]	0.02	0.02	[0.02]	[0.04]	[0.02]	0.04	[0.09]	0.03	0.07	0.0
UB-A	C	Economizer Ash		[0.005]	[0.01]	[0.01]	[0.01]	[0.03]	0.02	0.02	[0.01]	[0.02]	[0.01]	0.02	0.20	[0.02]	0.22	0.0
SSI-C	A	Filtrate			[0.0001]	[0.001]	[0.0001]	[0.0002]	[0.0001]	0.00		0.00	0.00	0.00	0.00	[0.0001]	0.01	0.0
SSI-G	A	Bottom Ash		[0.008]	[0.008]	[0.01]	[0.02]	[0.02]	0.01	0.01	[0.02]	[0.04]	[0.01]	0.02	0.03	0.01	0.06	0.0
BLD-A	A	Economizer Ash		[0.005]	[0.01]	[0.01]	[[0.02]	[0.01]	0.01	0.01	[0.01]	[0.02]	[0.01]	0.01	[0.01]	[0.01]	0.01	0.0
SSB-A	C	Multi-Clone Ash		[0.005]	[0.01]	[0.02]	[0.03]	0.09	0.07	0.16		[0.03]	[0.04]	[0.03]	0.04	0.02	0.06	0.0
OB-B	C	Bottom Ash		[0.04]	[0.07]	[0.01]	[0.02]	[0.01]	0.02	0.02	[0.01]	[0.02]	[0.01]	[0.02]	[0.04]	[0.003]	0.00	0.0
OB-A	C	Bottom Ash		[0.04]	[0.08]	[0.1]	[0.08]	[0.1]	0.07	0.07	[0.03]	[0.06]	[0.05]	[0.05]	[0.1]	[0.02]	0.00	0.0
SSI-C	A	Bottom ash			[0.01]	[0.01]	[0.009]	[0.02]	0.02	0.02		[0.07]	[0.02]	[0.03]	[0.02]	[0.01]	0.00	0.0
SSI-A	A	Bottom Ash		[0.993]	[0.003]	[0.007]	[0.029]	[0.017]	[0.020]	0.00		[0.004]	[0.007]	[0.023]	[0.017]	[0.02]	0.00	0.0
BLD-C	A	ESP Ash			[0.01]	[0.01]	[0.01]	[0.02]	[0.03]	0.00		[0.04]	[0.01]	[0.03]	[0.02]	[0.01]	0.00	0.0
UB-B	B	Baghouse Ash		[0.01]	[0.01]	[0.01]	[0.05]	[0.04]	0.07	0.07		[0.02]	[0.01]	[0.03]	[0.01]	[0.01]	0.00	0.0
BLD-E	A	ESP Ash		[0.009]	[0.009]	[0.007]	[0.01]	[0.01]	[0.008]	0.00	[0.02]	[0.04]	[0.008]	[0.02]	[0.008]	[0.004]	0.00	0.0
SSB-C	C	Bottom Ash		[0.02]	[0.03]	[0.02]	[0.01]	[0.006]	0.01	0.01	[0.01]	[0.02]	[0.02]	[0.01]	[0.004]	[0.01]	0.00	0.0
CX-A	C	ESP Ash		[0.003]	[0.003]	[0.01]	[0.02]	[0.02]	0.13	0.13		0.05	[0.03]	[0.02]	[0.02]	[0.01]	0.05	0.0
SLD-B	C	Scrubber Water	Analyzed by Dow[c]	[0.008]	[0.013]			[0.02]	[0.012]	0.00	[0.02]	[0.036]					0.00	0.0
CX-B	C	ESP Ash		[0.005]	[0.01]	[0.01]	[0.02]	[0.02]	[0.01]	0.00		0.02	[0.01]	[0.03]	[0.01]	[0.01]	0.02	0.0
WS-A	C	Bottom Ash		[0.01]	[0.03]	[0.02]	[0.05]	[0.03]	0.04	0.04	[0.02]	[0.03]	[0.02]	[0.02]	[0.04]	[0.01]	0.00	0.0
WS-B	C	Bottom Ash		[0.005]	[0.01]	[0.008]	[0.009]	[0.01]	[0.01]	0.00	[0.005]	[0.009]	[0.01]	[0.005]	[0.01]	[0.009]	0.00	0.0
CR-A	C	Afterburner Ash		[0.005]	[0.01]	[0.01]	[0.02]	[0.04]	0.03	0.03	[0.01]	[0.02]	[0.009]	[0.01]	[0.01]	[0.006]	0.00	0.0
RHD-A	C	Baghouse Ash		[0.01]	[0.02]	[0.02]	[0.02]	[0.01]	[0.008]	0.00		0.20	0.10	0.05	[0.008]	[0.01]	0.35	0.0
AHI-D	C	Bottom Ash		[0.01]	[0.02]	[0.04]	[0.04]	[0.04]	0.05	0.05	[0.01]	[0.02]	[0.04]	[0.04]	0.03	0.05	0.00	0.0
WFD-A	B	Bottom Ash	Primary chamber		[0.04]	[0.03]	[0.03]	[0.4]	0.02	0.02		[0.06]	[0.02]	[0.02]	[0.02]	[0.01]	0.00	0.0
SLD-B	C	Filterable solids[d]		[0.1]	[0.1]	[0.1]	[0.09]	[0.1]	0.10	0.10	[0.005]	[0.01]	[0.1]	[0.1]	[0.09]	[0.06]	0.00	---
BC-A	UR	Bottom Ash		[0.005]	[0.01]	[0.01]	[0.01]	[0.04]	[0.02]	0.00	[0.02]	[0.04]	[0.04]	[0.04]	[0.05]	[0.02]	0.00	0.0
SSI-I	A	Bottom Ash		[0.04]	[0.08]	[0.02]	[0.02]	[0.02]	0.03	0.03	[0.02]	[0.04]	[0.01]	[0.04]	[0.03]	[0.01]	0.00	0.0
WFD-H	B	Multi-Clone Ash		[0.2]	[0.05]	[0.06]	[0.05]	[0.04]	[0.04]	0.00	[0.1]	[0.20]	[0.06]	[0.07]	[0.02]	[0.01]	0.00	0.0
BLD-D	A	ESP Ash		[0.002]	[0.003]	[0.007]	[0.01]	[0.009]	0.008	0.01	[0.004]	[0.007]	[0.006]	[0.01]	[0.01]	[0.004]	0.00	0.0
HMI-A	C	Bottom Ash		[0.005]	[0.01]	[0.009]	[0.006]	[0.01]	[0.01]	0.00	[0.003]	[0.005]	[0.01]	[0.01]	[0.009]	[0.004]	0.00	0.0
SSB-C	C	Multi-Clone Ash		[0.005]	[0.01]	[0.01]	[0.01]	[0.01]	0.01	0.01		[0.02]	[0.02]	[0.01]	[0.01]	[0.02]	0.00	0.0
CR-D	C	Bottom Ash		[0.01]	[0.03]	[0.02]	[0.04]	[0.03]	0.07	0.07	[0.02]	[0.04]	[0.02]	[0.01]	[0.02]	[0.01]	0.00	0.0
WS-C	C	Bottom Ash		[0.005]	[0.01]	[0.01]	[0.01]	[0.006]	0.01	0.01	[0.005]	[0.01]	[0.01]	[0.01]	[0.003]	[0.002]	0.00	0.0
WFD-G	B	Multi-Clone Ash		[0.02]	[0.03]	[0.02]	[0.02]	[0.03]	[0.05]	0.00	[0.02]	[0.04]	[0.06]	[0.02]	[0.04]	[0.009]	0.00	0.0
SLD-C	C	Filterable solids[d]		[0.07]	[0.13]	[0.11]	[0.05]	0.20	0.20	0.40	[0.120]	[0.24]	[0.15]	[0.13]	[0.1]	[0.2]	0.00	---
CB-A	C	Multi-Clone Ash		[0.005]	[0.009]	[0.006]	[0.007]	[0.006]	0.02	0.02	[0.005]	[0.005]	[0.005]	[0.006]	[0.01]	[0.01]	0.00	0.0
BLD-G	A	ESP Ash		[0.01]	[0.02]	[0.02]	[0.01]	[0.01]	0.008	0.01		0.01	[0.03]	[0.02]	[0.01]	[0.08]	0.00	0.0
WFB-E	B	Multi-Clone Ash		[0.01]	[0.02]	[0.03]	[0.01]	[0.02]	0.03	0.03	[0.03]	[0.06]	[0.03]	[0.01]	[0.001]	[0.006]	0.00	0.0
WFB-A	D	Bottom Ash	Secondary Chamber	[0.01]	[0.03]	[0.03]	[0.11]	[0.1]	0.08	0.08	[0.01]	[0.04]	[0.02]	[0.03]	[0.02]	[0.02]	0.00	0.0
UB-D	D	ESP Ash		[0.008]	[0.008]	[0.01]	[0.01]	[0.01]	0.01	0.01	[0.005]	[0.01]	[0.01]	[0.01]	0.01	[0.004]	0.01	0.0
WFB-F	B	Multi-Clone Ash		[0.02]	[0.04]	[0.04]	[0.05]	[0.05]	0.06	0.06		0.12	[0.04]	[0.03]	[0.04]	[0.02]	0.12	0.0
SSB-B	C	Multi-Clone Ash		[0.01]	[0.03]	[0.01]	[0.02]	[0.01]	[0.01]	0.00	[0.03]	[0.06]	[0.03]	[0.06]	[0.01]	[0.01]	0.00	0.0
HSWI-A	B	ESP Ash		SAMPLE NOT ANALYZED.														
BLD-F	A	Economizer Ash			[0.02]	[0.01]	[0.01]	[0.009]	[0.008]	0.00		[0.03]	[0.007]	[0.03]	[0.01]	[0.005]	0.00	0.0

a Total = The sum of the tetra- thru octa- chlorinated homologues.

b Results in brackets are minimum detection limits for congeners that were not detected.

c Results reported by Dow under the Region V program included only the tetra, hexa, hepta, and octa-CDDs and 2378 TCDF. Results are reported on a solids basis.

d Results reported for this sample are in nanograms detected, not ng/g.

UR - Category is not ranked.

ranking of Category A is not confirmed by the test data since only two of the 15 rank A sites were above 1 ppb of 2378-TCDD toxic equivalents. The Rank B and Rank C category assumptions were confirmed. In addition, three of the Rank D sites (MSWI-D, MSWI-B and MSWI-C) were in the top 19, as expected.

Based on the ash sampling program results, source test sites in the Rank B categories had the highest PCDD/PCDF concentrations (WFB-A, WRI-A, MET-A). Some ash sampling sites in the Rank D category (MSWI-C, MSWI-B, and MSWI-D) also had some of the highest PCDD/PCDF concentrations.

CHAPTER 9

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APPENDIX A

TIER 4 EMISSIONS DATA

A.1 Summary of PCDD/PCDF Emission Concentrations (As-Measured Basis)

A.2 Summary of PCDD/PCDF Emission Concentrations (Normalized to 3% Oxygen)

A.3 Summary of PCDD/PCDF Emissions Per Unit of Feed

A.4 Error Analysis: Control Device Efficiency Calculations

APPENDIX A.1

Summary of PCDD/PCDF Emission Concentrations
(As-Measured Basis)

TABLE A.1.1. SITE 1 (SSI-A)/OUTLET
DIOXIN/FURAN EMISSION CONCENTRATIONS
(As-measured values)

Dioxin/Furan Isomer	Isomer Concentration in Flue Gas (ng/dscm) Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	5.08E-03	9.12E-03	4.49E-03	6.23E-03
Other TCDD	1.70E+00	1.62E+00	1.38E+00	1.56E+00
Penta-CDD	2.12E-02	4.19E-02	ND(3.04E-02)	2.10E-02
Hexa-CDD	ND(4.06E-02)	1.24E-01	1.10E-01	7.80E-02
Hepta-CDD	3.79E-01	3.03E-01	4.13E-01	3.65E-01
Octa-CDD	9.02E-01	5.50E-01	9.78E-01	8.10E-01
Total PCDD	3.01E+00	2.65E+00	2.88E+00	2.84E+00
FURANS				
2378 TCDF	NR	NR	NR	NR
Other TCDF	4.91E+00	4.46E+00	4.99E+00	4.79E+00
Penta-CDF	1.59E+00	1.28E+00	1.51E+00	1.46E+00
Hexa-CDF	ND(9.44E-02)	ND(7.30E-02)	7.29E-02	2.43E-02
Hepta-CDF	6.21E-02	7.82E-02	8.19E-02	7.41E-02
Octa-CDF	ND(5.65E-02)	3.65E-02	ND(4.11E-02)	1.22E-02
Total PCDF	6.56E+00	5.86E+00	6.66E+00	6.36E+00

NOTE: Isomer concentrations shown are at as-measured oxygen conditions.
NR = not reported by Troika.
ND = not detected (detection limit in parentheses).
ng = 1.0E-09g
6000 operating hours per year

TABLE A.1.2. SITE 2 (ISW-A)/OUTLET DIOXIN/FURAN EMISSION CONCENTRATIONS

(As-measured values)

Dioxin/Furan Isomer	Isomer Concentration in Flue Gas (ng/dscm) Run 01	Run 03	Run 04	Avg.
DIOXINS				
2378 TCDD	4.12E-01	1.47E+00	1.01E+00	9.67E-01
Other TCDD	6.80E+00	2.61E+01	1.68E+01	1.66E+01
Penta-CDD	1.03E+01	3.26E+01	2.29E+01	2.20E+01
Hexa-CDD	2.02E+01	3.94E+01	3.08E+01	3.01E+01
Hepta-CDD	2.41E+01	5.03E+01	6.33E+01	4.59E+01
Octa-CDD	9.90E+00	1.77E+01	1.14E+01	1.30E+01
Total PCDD	7.18E+01	1.68E+02	1.46E+02	1.29E+02
FURANS				
2378 TCDF	2.27E+00	6.53E+00	4.46E+00	4.42E+00
Other TCDF	6.95E+01	1.46E+02	1.36E+02	1.17E+02
Penta-CDF	7.24E+01	1.43E+02	1.50E+02	1.22E+02
Hexa-CDF	1.15E+02	1.32E+02	1.41E+02	1.30E+02
Hepta-CDF	6.37E+01	8.97E+01	1.21E+02	9.15E+01
Octa-CDF	1.09E+01	1.83E+01	1.24E+01	1.39E+01
Total PCDF	3.34E+02	5.36E+02	5.65E+02	4.78E+02

NOTE: Isomer concentrations shown are at as-measured oxygen conditions.

ND = not detected (detection limit in parentheses).
ng = 1.0E-09g
2200 operating hours per year

TABLE A.1.3. SITE 3 (SSI-B)/OUTLET
DIOXIN/FURAN EMISSION CONCENTRATIONS
(As-measured values)

Dioxin/Furan Isomer	Isomer Concentration in Flue Gas (ng/dscm)			
	Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	ND(1.15E-02)	ND(6.00E-02)	ND(1.15E-02)	.00E+00
Other TCDD	1.92E-01	ND(6.00E-02)	2.87E-02	7.37E-02
Penta-CDD	ND(1.92E-02)	ND(4.50E-02)	ND(5.75E-02)	.00E+00
Hexa-CDD	ND(1.85E-01)	ND(1.02E-01)	ND(8.62E-03)	.00E+00
Hepta-CDD	1.15E-01	ND(6.75E-02)	ND(4.02E-02)	3.85E-02
Octa-CDD	3.08E-01	1.75E-01	1.72E-01	2.18E-01
Total PCDD	6.15E-01	1.75E-01	2.01E-01	3.31E-01
FURANS				
2378 TCDF	7.31E-01	2.50E-01	4.02E-01	4.61E-01
Other TCDF	7.50E+00	1.52E+00	2.67E+00	3.90E+00
Penta-CDF	2.08E+00	ND(4.50E-02)	7.18E-01	9.32E-01
Hexa-CDF	8.46E-01	ND(5.75E-02)	ND(2.13E-01)	2.82E-01
Hepta-CDF	ND(2.38E-01)	ND(7.25E-02)	ND(2.01E-02)	.00E+00
Octa-CDF	3.85E-02	ND(1.25E-02)	ND(1.72E-02)	1.28E-02
Total PCDF	1.12E+01	1.77E+00	3.79E+00	5.59E+00

NOTE: Isomer concentrations shown are at as-measured oxygen conditions.

ND = not detected (detection limit in parentheses).
ng = 1.0E-09g
8760 operating hours per year

TABLE A.1.4a. SITE 4 (BLB-A)/INLET
DIOXIN/FURAN EMISSION CONCENTRATIONS
(As-measured values)

Dioxin/Furan Isomer	Isomer Concentration in Flue Gas (ng/dscm)			
	Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	ND(1.94E-02)	ND(1.98E-02)	ND(7.47E-02)	.00E+00
Other TCDD	ND(1.94E-02)	1.98E-02	ND(7.47E-02)	6.61E-03
Penta-CDD	ND(7.52E-02)	ND(2.38E-02)	ND(9.96E-02)	.00E+00
Hexa-CDD	1.21E-01	7.94E-02	ND(3.90E-01)	6.69E-02
Hepta-CDD	2.91E-01	1.98E-01	5.81E-01	3.57E-01
Octa-CDD	8.01E-01	6.35E-01	2.03E+00	1.16E+00
Total PCDD	1.21E+00	9.33E-01	2.61E+00	1.59E+00
FURANS				
2378 TCDF	ND(1.46E-02)	ND(7.94E-02)	ND(1.66E-01)	.00E+00
Other TCDF	2.43E-01	1.98E-01	4.15E-01	2.85E-01
Penta-CDF	3.16E-01	2.38E-01	ND(6.14E-01)	1.85E-01
Hexa-CDF	4.37E-01	3.97E-01	7.88E-01	5.41E-01
Hepta-CDF	2.43E-01	1.19E-01	3.73E-01	2.45E-01
Octa-CDF	7.28E-02	7.94E-02	ND(2.61E-01)	5.07E-02
Total PCDF	1.31E+00	1.03E+00	1.58E+00	1.31E+00

NOTE: Isomer concentrations shown are at as-measured oxygen conditions.

ND = not detected (detection limit in parentheses).
ng = 1.0E-09g
8760 operating hours per year

TABLE A.1.4b. SITE 4 (BLB-A)/OUTLET
DIOXIN/FURAN EMISSION CONCENTRATIONS
(As-measured values)

Dioxin/Furan Isomer	Isomer Concentration in Flue Gas (ng/dscm)			
	Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	ND(6.00E-02)	ND(1.69E-02)	ND(1.88E-02)	.00E+00
Other TCDD	ND(6.00E-02)	5.06E-02	ND(1.88E-02)	1.69E-02
Penta-CDD	ND(2.51E-02)	ND(2.02E-02)	ND(3.77E-02)	.00E+00
Hexa-CDD	1.55E-01	ND(5.40E-02)	ND(4.11E-02)	5.16E-02
Hepta-CDD	3.09E-01	8.43E-02	8.56E-02	1.60E-01
Octa-CDD	7.16E-01	3.71E-01	2.23E-01	4.36E-01
Total PCDD	1.18E+00	5.06E-01	3.08E-01	6.65E-01
FURANS				
2378 TCDF	ND(7.74E-03)	ND(3.37E-02)	ND(1.71E-02)	.00E+00
Other TCDF	3.29E-01	5.06E-02	3.42E-02	1.38E-01
Penta-CDF	1.55E-01	ND(3.88E-02)	ND(2.23E-02)	5.16E-02
Hexa-CDF	1.35E-01	5.06E-02	ND(8.73E-02)	6.20E-02
Hepta-CDF	1.93E-01	1.69E-01	5.14E-02	1.38E-01
Octa-CDF	7.74E-02	2.53E-01	1.71E-02	1.16E-01
Total PCDF	8.90E-01	5.23E-01	1.03E-01	5.05E-01

NOTE: Isomer concentrations shown are at as-measured oxygen conditions.

ND = not detected (detection limit in parentheses).
ng = 1.0E-09g
8760 operating hours per year

TABLE A.1.5a. SITE 5 (BLB-B)/INLET
DIOXIN/FURAN EMISSION CONCENTRATIONS
(As-measured values)

Dioxin/Furan Isomer	Isomer Concentration in Flue Gas (ng/dscm)			
	Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	ND(3.95E-02)	ND(6.25E-02)	ND(2.43E-02)	.00E+00
Other TCDD	ND(3.95E-02)	ND(6.25E-02)	ND(2.43E-02)	.00E+00
Penta-CDD	ND(3.95E-02)	ND(6.94E-03)	ND(8.68E-02)	.00E+00
Hexa-CDD	ND(3.95E-02)	ND(8.68E-02)	2.08E-01	6.94E-02
Hepta-CDD	1.75E-01	7.29E-01	6.81E+00	2.57E+00
Octa-CDD	7.02E-01	2.33E+00	3.42E+01	1.24E+01
Total PCDD	8.77E-01	3.06E+00	4.13E+01	1.51E+01
FURANS				
2378 TCDF	4.39E-02	ND(6.25E-02)	6.94E-02	3.78E-02
Other TCDF	4.39E-02	ND(6.25E-02)	4.51E-01	1.65E-01
Penta-CDF	ND(1.05E-01)	ND(3.47E-02)	ND(8.68E-02)	.00E+00
Hexa-CDF	8.77E-02	1.04E-01	2.43E-01	1.45E-01
Hepta-CDF	4.39E-02	3.47E-01	6.25E-01	3.39E-01
Octa-CDF	4.39E-02	2.43E-01	4.51E-01	2.46E-01
Total PCDF	2.63E-01	6.94E-01	1.84E+00	9.33E-01

NOTE: Isomer concentrations shown are at as-measured oxygen conditions.

ND = not detected (detection limit in parentheses).
ng = 1.0E-09g
8760 operating hours per year

TABLE A.1.5b. SITE 5 (BLB-B)/OUTLET
DIOXIN/FURAN EMISSION CONCENTRATIONS
(As-measured values)

Dioxin/Furan Isomer	Isomer Concentration in Flue Gas (ng/dscm)			
	Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	ND(3.01E-02)	ND(1.18E-02)	ND(2.49E-02)	.00E+00
Other TCDD	ND(3.01E-02)	ND(1.18E-02)	ND(2.49E-02)	.00E+00
Penta-CDD	ND(4.51E-02)	ND(3.29E-02)	ND(1.36E-01)	.00E+00
Hexa-CDD	1.88E-01	ND(8.47E-02)	6.79E-02	8.53E-02
Hepta-CDD	3.38E-01	1.65E-01	1.58E-01	2.20E-01
Octa-CDD	1.05E+00	5.41E-01	5.43E-01	7.12E-01
Total PCDD	1.58E+00	7.06E-01	7.69E-01	1.02E+00
FURANS				
2378 TCDF	ND(3.76E-02)	ND(4.00E-02)	2.26E-02	7.54E-03
Other TCDF	2.63E-01	ND(4.00E-02)	6.79E-02	1.10E-01
Penta-CDF	ND(2.74E-01)	ND(3.29E-02)	ND(1.36E-01)	.00E+00
Hexa-CDF	7.14E-01	ND(1.36E-01)	1.36E-01	2.83E-01
Hepta-CDF	2.63E-01	7.06E-02	9.05E-02	1.41E-01
Octa-CDF	7.52E-02	4.71E-02	4.52E-02	5.58E-02
Total PCDF	1.32E+00	1.18E-01	3.62E-01	5.98E-01

NOTE: Isomer concentrations shown are at as-measured oxygen conditions.

ND = not detected (detection limit in parentheses).
ng = 1.0E-09g
8760 operating hours per year

TABLE A.1.6a. SITE 6 (WRI-A)/OUTLET
(Wire only)
DIOXIN/FURAN EMISSION CONCENTRATIONS
(As-measured values)

Dioxin/Furan Isomer	Isomer Concentration in Flue Gas (ng/dscm)			
	Run 01	Run 02	Run 06	Avg.
DIOXINS				
2378 TCDD	NR	NR	9.29E-02	9.29E-02
Other TCDD	5.16E-01	NR	1.24E+00	8.78E-01
Penta-CDD	NR	NR	2.04E+00	2.04E+00
Hexa-CDD	3.10E+00	NR	8.82E+00	5.96E+00
Hepta-CDD	3.18E+01	2.15E+01	1.39E+02	6.41E+01
Octa-CDD	1.54E+01	1.24E+01	1.26E+02	5.13E+01
Total PCDD	5.09E+01	3.39E+01	2.77E+02	1.24E+02
FURANS				
2378 TCDF	NR	NR	3.72E-01	3.72E-01
Other TCDF	3.89E+00	9.63E+00	1.63E+01	9.94E+00
Penta-CDF	5.28E+00	NR	2.66E+01	1.59E+01
Hexa-CDF	1.23E+01	3.18E+00	6.06E+01	2.54E+01
Hepta-CDF	4.74E+01	6.12E+01	2.54E+02	1.21E+02
Octa-CDF	2.70E+01	2.92E+01	9.97E+01	5.20E+01
Total PCDF	9.58E+01	1.03E+02	4.57E+02	2.25E+02

NOTE: Isomer concentrations shown are at as-measured oxygen conditions.
NR = not reported by Troika.
ND = not detected (detection limit in parentheses).
ng = 1.0E-09g
2080 operating hours per year

NOTE: Several recoveries for the MM5 train samples did not meet the quality assurance requirements for all four labelled compounds. Problems with method efficiency resulted from contamination present in the sample extracts and corresponding difficulties in achieving acceptable chromatographic separations. The reported analytical results may actually represent lower bounds on the true values. See Section 7.3.1 for more details.

TABLE A.1.6b. SITE 6 (WRI-A)/OUTLET
(Wire and Transformers)
DIOXIN/FURAN EMISSION CONCENTRATIONS
(As-measured values)

Dioxin/Furan Isomer	Isomer Concentration in Flue Gas (ng/dscm) Run 03	Run 04	Run 05	Avg.
DIOXINS				
2378 TCDD	5.12E-02	NR	1.15E-01	8.31E-02
Other TCDD	2.30E-01	1.32E+00	1.53E+00	1.03E+00
Penta-CDD	4.27E+00	NR	3.23E+00	3.75E+00
Hexa-CDD	4.95E+01	NR	5.50E+00	2.75E+01
Hepta-CDD	3.41E+02	6.19E+01	2.07E+01	1.41E+02
Octa-CDD	1.21E+03	6.27E+01	1.84E+01	4.32E+02
Total PCDD	1.61E+03	1.26E+02	4.95E+01	6.05E+02
FURANS				
2378 TCDF	4.09E-01	NR	8.07E-01	6.08E-01
Other TCDF	2.59E+01	5.42E+01	2.15E+01	3.39E+01
Penta-CDF	5.46E+01	NR	1.29E+01	3.38E+01
Hexa-CDF	1.77E+02	3.78E+01	2.10E+01	7.85E+01
Hepta-CDF	3.86E+02	2.65E+02	6.17E+01	2.38E+02
Octa-CDF	8.08E+02	1.37E+02	4.61E+01	3.30E+02
Total PCDF	1.45E+03	4.93E+02	1.64E+02	7.15E+02

NOTE: Isomer concentrations shown are at as-measured oxygen conditions.
NR = not reported by Troika.
ND = not detected (detection limit in parentheses).
ng = 1.0E-09g
2080 operating hours per year

NOTE: Several recoveries for the MM5 train samples did not meet the quality assurance requirements for all four labelled compounds. Problems with method efficiency resulted from contamination present in the sample extracts and corresponding difficulties in achieving acceptable chromatographic separations. The reported analytical results may actually represent lower bounds on the true values. See Section 7.3.1 for more details.

TABLE A.1.7a. SITE 7 (WFB-A)/INLET DIOXIN/FURAN EMISSION CONCENTRATIONS (As-measured values)

Dioxin/Furan Isomer	Isomer Concentration in Flue Gas (ng/dscm) Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	NR	3.70E-01	3.18E-01	3.44E-01
Other TCDD	4.78E+00	8.72E+00	1.24E+01	8.62E+00
Penta-CDD	NR	1.02E+01	1.16E+01	1.09E+01
Hexa-CDD	4.92E+00	1.02E+01	1.18E+01	8.98E+00
Hepta-CDD	9.07E+00	8.12E+00	6.62E+00	7.94E+00
Octa-CDD	8.77E+00	1.97E+00	1.73E+00	4.16E+00
Total PCDD	2.75E+01	3.96E+01	4.45E+01	4.09E+01
FURANS				
2378 TCDF	NR	2.31E+00	2.31E+00	2.31E+00
Other TCDF	2.98E+01	4.33E+01	4.75E+01	4.02E+01
Penta-CDF	4.70E+00	1.65E+01	1.68E+01	1.27E+01
Hexa-CDF	3.25E+00	5.90E+00	6.81E+00	5.32E+00
Hepta-CDF	1.31E+00	2.54E+00	2.23E+00	2.02E+00
Octa-CDF	ND(3.17E+00)	2.56E-01	2.31E-01	1.63E-01
Total PCDF	3.91E+01	7.08E+01	7.59E+01	6.27E+01

NOTE: Isomer concentrations shown are at as-measured oxygen conditions.

NR = not reported by Troika.
ND = not detected (detection limit in parentheses).
ng = 1.0E-09g
8760 operating hours per year

TABLE A.1.7b. SITE 7 (WFB-A)/OUTLET
DIOXIN/FURAN EMISSION CONCENTRATIONS
(As-measured values)

Dioxin/Furan Isomer	Isomer Concentration in Flue Gas (ng/dscm) Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	6.01E-02	8.80E-02	9.38E-02	8.06E-02
Other TCDD	1.39E+01	2.07E+01	7.58E+00	1.41E+01
Penta-CDD	1.77E+01	1.90E+01	6.08E+00	1.42E+01
Hexa-CDD	1.82E+01	1.94E+01	6.23E+00	1.46E+01
Hepta-CDD	9.91E+00	1.46E+01	9.44E+00	1.13E+01
Octa-CDD	2.82E+00	3.70E+00	3.22E+00	3.25E+00
Total PCDD	6.26E+01	7.75E+01	3.26E+01	5.76E+01
FURANS				
2378 TCDF	3.90E-01	5.87E-01	5.63E-01	5.13E-01
Other TCDF	9.88E+00	1.68E+01	6.70E+00	1.11E+01
Penta-CDF	6.79E+00	9.93E+00	4.00E+00	6.90E+00
Hexa-CDF	4.26E+00	6.66E+00	1.09E+00	4.00E+00
Hepta-CDF	1.80E+00	3.06E+00	1.00E+00	1.96E+00
Octa-CDF	3.60E-01	2.49E-01	1.88E-01	2.66E-01
Total PCDF	2.35E+01	3.73E+01	1.35E+01	2.48E+01

NOTE: Isomer concentrations shown are at as-measured oxygen conditions.

ND = not detected (detection limit in parentheses).
ng = 1.0E-09g
8760 operating hours per year

TABLE A.1.8a. SITE 8 (BLB-C)/INLET
DIOXIN/FURAN EMISSION CONCENTRATIONS
(As-measured values)

Dioxin/Furan Isomer	Isomer Concentration in Flue Gas (ng/dscm)			
	Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	ND(.00E+00)	ND(.00E+00)	ND(.00E+00)	.00E+00
Other TCDD	8.10E-01	3.26E-01	3.86E-01	5.07E-01
Penta-CDD	1.03E+00	4.81E-01	4.50E-01	6.53E-01
Hexa-CDD	1.59E+00	1.02E+00	1.09E+00	1.24E+00
Hepta-CDD	1.40E+00	7.92E-01	7.72E-01	9.88E-01
Octa-CDD	9.35E-01	6.52E-01	6.75E-01	7.54E-01
Total PCDD	5.76E+00	3.28E+00	3.38E+00	4.14E+00
FURANS				
2378 TCDF	ND(.00E+00)	ND(.00E+00)	ND(.00E+00)	.00E+00
Other TCDF	6.17E+00	6.37E-01	7.07E-01	2.50E+00
Penta-CDF	5.89E+00	3.73E-01	ND(4.18E-01)	2.09E+00
Hexa-CDF	4.36E+00	5.12E-01	5.14E-01	1.80E+00
Hepta-CDF	1.15E+00	1.86E-01	1.61E-01	5.00E-01
Octa-CDF	1.56E-01	9.32E-02	ND(9.65E-02)	8.30E-02
Total PCDF	1.77E+01	1.80E+00	1.38E+00	6.97E+00

NOTE: Isomer concentrations shown are at as-measured oxygen conditions.

ND = not detected (detection limit in parentheses).
ng = 1.0E-09g
8760 operating hours per year

TABLE A.1.8b. SITE 8 (BLB-C)/OUTLET
DIOXIN/FURAN EMISSION CONCENTRATIONS
(As-measured values)

Dioxin/Furan Isomer	Isomer Concentration in Flue Gas (ng/dscm)			
	Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	ND(9.57E-03)	ND(4.52E-03)	ND(2.51E-03)	.00E+00
Other TCDD	4.78E-02	1.24E-01	6.28E-02	7.84E-02
Penta-CDD	ND(2.39E-02)	2.49E-01	1.01E-01	1.16E-01
Hexa-CDD	7.18E-02	4.75E-01	2.39E-01	2.62E-01
Hepta-CDD	1.20E-01	1.38E+00	4.77E-01	6.59E-01
Octa-CDD	2.87E-01	2.71E+00	4.52E-01	1.15E+00
Total PCDD	5.26E-01	4.94E+00	1.33E+00	2.27E+00
FURANS				
2378 TCDF	ND(1.44E-02)	1.81E-02	ND(2.51E-03)	6.03E-03
Other TCDF	1.20E-01	2.99E-01	3.39E-01	2.52E-01
Penta-CDF	ND(4.78E-02)	2.49E-01	4.77E-01	2.42E-01
Hexa-CDF	1.20E-01	2.60E-01	5.15E-01	2.98E-01
Hepta-CDF	9.57E-02	3.85E-01	3.77E-01	2.86E-01
Octa-CDF	4.78E-02	4.52E-02	5.03E-02	4.78E-02
Total PCDF	3.83E-01	1.26E+00	1.76E+00	1.13E+00

NOTE: Isomer concentrations shown are at as-measured oxygen conditions.

ND = not detected (detection limit in parentheses).
ng = 1.0E-09g
8760 operating hours per year

TABLE A.1.9a. SITE 9 (CRF-A)/INLET
DIOXIN/FURAN EMISSION CONCENTRATIONS
(As-measured values)

Dioxin/Furan Isomer	Isomer Concentration in Flue Gas (ng/dscm) Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	5.12E-02	4.95E-02	8.87E-02	6.31E-02
Other TCDD	9.21E-01	8.66E-01	3.08E+00	1.62E+00
Penta-CDD	2.02E+00	4.70E-01	2.51E+00	1.67E+00
Hexa-CDD	6.04E+00	2.90E+00	3.64E+00	4.19E+00
Hepta-CDD	7.95E+00	6.26E+00	3.97E+00	6.06E+00
Octa-CDD	9.18E+00	1.06E+01	2.13E+00	7.32E+00
Total PCDD	2.62E+01	2.12E+01	1.54E+01	2.09E+01
FURANS				
2378 TCDF	8.95E-01	1.16E+00	9.31E-01	9.97E-01
Other TCDF	1.22E+01	1.73E+01	1.40E+01	1.45E+01
Penta-CDF	8.77E+00	9.36E+00	1.25E+01	1.02E+01
Hexa-CDF	1.04E+01	1.23E+01	1.14E+01	1.13E+01
Hepta-CDF	7.29E+00	1.11E+01	8.96E+00	9.12E+00
Octa-CDF	3.35E+00	4.88E+00	3.46E+00	3.90E+00
Total PCDF	4.29E+01	5.60E+01	5.12E+01	5.01E+01

NOTE: Isomer concentrations shown are at as-measured oxygen conditions.

ND = not detected (detection limit in parentheses).
ng = 1.0E-09g
8760 operating hours per year

TABLE A.1.9b. SITE 9 (CRF-A)/OUTLET
DIOXIN/FURAN EMISSION CONCENTRATIONS
(As-measured values)

Dioxin/Furan Isomer	Isomer Concentration in Flue Gas (ng/dscm)			
	Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	ND(1.79E-01)	ND(5.29E-02)	ND(4.61E-02)	.00E+00
Other TCDD	5.87E-01	ND(7.94E-02)	6.91E-02	2.19E-01
Penta-CDD	3.83E-01	1.32E-01	ND(1.15E-01)	1.72E-01
Hexa-CDD	6.12E-01	3.17E-01	2.07E-01	3.79E-01
Hepta-CDD	4.59E-01	3.44E-01	2.30E-01	3.45E-01
Octa-CDD	4.08E-01	2.91E-01	2.30E-01	3.10E-01
Total PCDD	2.45E+00	1.08E+00	7.37E-01	1.42E+00
FURANS				
2378 TCDF	ND(1.53E-01)	ND(1.59E-01)	ND(9.22E-02)	.00E+00
Other TCDF	5.36E-01	5.29E-01	3.23E-01	4.62E-01
Penta-CDF	1.53E-01	2.91E-01	ND(1.15E-01)	1.48E-01
Hexa-CDF	2.81E-01	2.12E-01	1.84E-01	2.26E-01
Hepta-CDF	3.32E-01	2.12E-01	1.61E-01	2.35E-01
Octa-CDF	2.30E-01	1.32E-01	2.53E-01	2.05E-01
Total PCDF	1.53E+00	1.38E+00	9.22E-01	1.28E+00

NOTE: Isomer concentrations shown are at as-measured oxygen conditions.

ND = not detected (detection limit in parentheses).
ng = 1.0E-09g
8760 operating hours per year

TABLE A.1.10. SITE 10 (MET-A)/OUTLET DIOXIN/FURAN EMISSION CONCENTRATIONS (As-measured values)

Dioxin/Furan Isomer	Isomer Concentration in Flue Gas (ng/dscm) Run 02	Run 03	Run 04	Avg.
DIOXINS				
2378 TCDD	1.75E+01	8.50E+00	5.77E+00	1.06E+01
Other TCDD	3.53E+01	7.01E+01	5.40E+01	5.31E+01
Penta-CDD	6.28E+01	1.16E+02	7.45E+01	8.46E+01
Hexa-CDD	1.45E+02	1.08E+02	6.76E+01	1.07E+02
Hepta-CDD	1.09E+02	2.93E+02	1.48E+02	1.84E+02
Octa-CDD	6.51E+01	1.85E+02	1.06E+02	1.19E+02
Total PCDD	4.36E+02	7.81E+02	4.56E+02	5.58E+02
FURANS				
2378 TCDF	1.86E+02	2.53E+02	2.65E+02	2.35E+02
Other TCDF	6.28E+02	8.90E+02	1.33E+03	9.48E+02
Penta-CDF	5.59E+02	9.27E+02	7.65E+02	7.50E+02
Hexa-CDF	5.10E+02	3.04E+02	2.58E+02	3.57E+02
Hepta-CDF	1.81E+02	5.32E+02	1.97E+02	3.03E+02
Octa-CDF	1.23E+02	3.60E+02	1.85E+02	2.22E+02
Total PCDF	2.19E+03	3.27E+03	3.00E+03	2.82E+03

NOTE: Isomer concentrations shown are at as-measured oxygen conditions.

ND = not detected (detection limit in parentheses).
ng = 1.0E-09g
8160 operating hours per year

NOTE: Surrogate recoveries could not be determined for Run 02 and 04 dioxin/furan samples because of the relatively large quantities of native CDD and CDF species present in the samples. The reported analytical results may actually represent lower bounds on the true values. See Section 7.3.1 for more details.

TABLE A.1.11a SITE 11 (DBR-A)/INLET
DIOXIN/FURAN EMISSION CONCENTRATIONS
(As-measured values)

Dioxin/Furan Isomer	Isomer Concentration in Flue Gas (ng/dscm)			
	Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	4.98E+00	3.06E+00	2.49E+00	3.51E+00
Other TCDD	1.72E+01	1.05E+01	2.06E+01	1.61E+01
Penta-CDD	2.60E+01	9.15E+00	3.11E+01	2.21E+01
Hexa-CDD	2.53E+01	5.94E+00	5.36E+01	2.83E+01
Hepta-CDD	1.42E+02	2.47E+00	5.32E+01	6.60E+01
Octa-CDD	5.29E+01	2.07E+00	1.16E+01	2.22E+01
Total PCDD	2.69E+02	3.32E+01	1.73E+02	1.58E+02
FURANS				
2378 TCDF	1.44E+01	1.16E+01	1.26E+01	1.29E+01
Other TCDF	1.94E+02	1.15E+02	2.67E+02	1.92E+02
Penta-CDF	1.69E+02	5.86E+01	1.67E+02	1.31E+02
Hexa-CDF	4.34E+01	1.08E+01	9.15E+01	4.86E+01
Hepta-CDF	1.32E+02	4.49E+00	5.18E+01	6.28E+01
Octa-CDF	4.26E+01	1.04E+00	1.23E+01	1.86E+01
Total PCDF	5.95E+02	2.02E+02	6.02E+02	4.66E+02

NOTE: Isomer concentrations shown are at as-measured oxygen conditions.

ND = not detected (detection limit in parentheses).
ng = 1.0E-09g
1536 operating hours per year

NOTE: Several recoveries for the MM5 train samples did not meet the quality assurance requirements for all four labelled compounds. Problems with method efficiency resulted from contamination present in the sample extracts and corresponding difficulties in achieving acceptable chromatographic separations. The reported analytical results may actually represent lower bounds on the true values. See Section 7.3.1 for more details.

TABLE A.1.11b. SITE 11 (DSR-A)/OUTLET
DIOXIN/FURAN EMISSION CONCENTRATIONS
(As-measured values)

Dioxin/Furan Isomer	Isomer Concentration in Flue Gas (ng/dscm) Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	2.86E-02	1.10E-02	2.58E-02	2.18E-02
Other TCDD	6.86E-01	3.47E-01	4.64E-01	4.99E-01
Penta-CDD	6.29E-01	1.10E-01	1.80E-01	3.06E-01
Hexa-CDD	5.71E-01	1.65E-01	2.71E-01	3.36E-01
Hepta-CDD	1.03E+00	3.03E-01	3.35E-01	5.56E-01
Octa-CDD	5.71E-01	3.03E-01	2.84E-01	3.86E-01
Total PCDD	3.51E+00	1.24E+00	1.56E+00	2.10E+00
FURANS				
2378 TCDF	6.86E-01	2.20E-01	2.32E-01	3.79E-01
Other TCDF	7.23E+00	5.96E+00	4.74E+00	5.98E+00
Penta-CDF	4.26E+00	1.79E+00	1.79E+00	2.61E+00
Hexa-CDF	2.11E+00	8.82E-01	7.86E-01	1.26E+00
Hepta-CDF	1.46E+00	5.79E-01	5.15E-01	8.50E-01
Octa-CDF	4.00E-01	1.65E-01	1.29E-01	2.31E-01
Total PCDF	1.61E+01	9.60E+00	8.20E+00	1.13E+01

NOTE: Isomer concentrations shown are at as-measured oxygen conditions.

ND = not detected (detection limit in parentheses).
ng = 1.0E-09g
1536 operating hours per year

TABLE A.1.12a. SITE 12 (SSI-C)/INLET
DIOXIN/FURAN EMISSION CONCENTRATIONS
(As-measured values)

Dioxin/Furan Isomer	Isomer Concentration in Flue Gas (ng/dscm) Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	NR	NR	NR	NR
Other TCDD	NR	1.39E+00	4.23E+00	2.81E+00
Penta-CDD	NR	ND(7.88E-01)	2.42E-01	1.21E-01
Hexa-CDD	NR	2.85E+00	3.32E+00	3.09E+00
Hepta-CDD	NR	2.16E+01	9.82E+00	1.57E+01
Octa-CDD	NR	2.37E+01	1.10E+01	1.74E+01
Total PCDD	NR	4.95E+01	2.86E+01	3.91E+01
FURANS				
2378 TCDF	NR	1.65E+01	3.94E+01	2.80E+01
Other TCDF	NR	4.00E+01	5.86E+01	4.93E+01
Penta-CDF	NR	3.60E+01	5.28E+01	4.44E+01
Hexa-CDF	NR	4.09E+00	4.95E+00	4.52E+00
Hepta-CDF	NR	3.92E+01	5.77E+00	2.25E+01
Octa-CDF	NR	3.93E+01	6.62E+00	2.30E+01
Total PCDF	NR	1.75E+02	1.68E+02	1.72E+02

NOTE: Isomer concentrations shown are at as-measured oxygen conditions.
NR = not reported by Troika.
ND = not detected (detection limit in parentheses).
ng = 1.0E-09g
8760 operating hours per year

NOTE: Several recoveries for the MM5 train samples did not meet the quality assurance requirements for all four labelled compounds. Problems with method efficiency resulted from contamination present in the sample extracts and corresponding difficulties in achieving acceptable chromatographic separations. The reported analytical results may actually represent lower bounds on the true values. See Section 7.3.1 for more details.

TABLE A.1.12b. SITE 12 (SSI-C)/OUTLET DIOXIN/FURAN EMISSION CONCENTRATIONS (As-measured values)

Dioxin/Furan Isomer	Isomer Concentration in Flue Gas (ng/dscm) Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	2.33E-02	2.30E-02	3.62E-02	2.75E-02
Other TCDD	1.26E+00	1.56E+00	1.85E+00	1.55E+00
Penta-CDD	1.33E-01	1.97E-01	3.08E-01	2.13E-01
Hexa-CDD	8.80E-01	1.56E+00	1.61E+00	1.35E+00
Hepta-CDD	1.30E+00	7.27E+00	3.55E+00	4.04E+00
Octa-CDD	1.06E+00	4.90E+00	2.83E+00	2.93E+00
Total PCDD	4.65E+00	1.55E+01	1.02E+01	1.01E+01
FURANS				
2378 TCDF	1.01E+01	9.18E+00	1.12E+01	1.02E+01
Other TCDF	2.25E+01	2.95E+01	3.41E+01	2.87E+01
Penta-CDF	1.67E+01	1.91E+01	2.44E+01	2.01E+01
Hexa-CDF	2.77E+00	8.59E+00	7.48E+00	6.28E+00
Hepta-CDF	1.30E+00	2.35E+01	1.00E+01	1.16E+01
Octa-CDF	5.98E-01	1.83E+01	7.36E+00	8.74E+00
Total PCDF	5.41E+01	1.08E+02	9.45E+01	8.56E+01

NOTE: Isomer concentrations shown are at as-measured oxygen conditions.

ND = not detected (detection limit in parentheses).
ng = 1.0E-09g
8760 operating hours per year

APPENDIX A.2

Summary of PCDD/PCDF Emission Concentrations (Normalized to 3% Oxygen)

APPENDIX A.2

The formula used for correction to 3 percent O_2 was:

$$P_c = P_m \times \frac{20.9 - K_o}{20.9 - \%O_2}$$

where: P_c = corrected value
P_m = measured value
K_o = reference O_2 concentration
$\%O_2$ = percent by volume of O_2

Reference:

Stack Sampling Technical Information / A Collection of Monographs and Papers, Volume 1, U.S. Environmental Protection Agency, Publication No. EPA-450/2-78-042a, October, 1978.

TABLE A.2.1. SITE 1 (SSI-A)/OUTLET
DIOXIN/FURAN EMISSION CONCENTRATIONS
(Values corrected to 3% O_2)

Dioxin/Furan Isomer	Isomer Concentration in Flue Gas (ng/dscm @ 3% oxygen)			
	Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	4.04E-02	7.78E-02	1.90E-02	4.58E-02
Other TCDD	1.35E+01	1.38E+01	5.83E+00	1.11E+01
Penta-CDD	1.68E-01	3.57E-01	ND(1.29E-01)	1.75E-01
Hexa-CDD	ND(3.23E-01)	1.06E+00	4.64E-01	5.09E-01
Hepta-CDD	3.02E+00	2.59E+00	1.75E+00	2.45E+00
Octa-CDD	7.18E+00	4.69E+00	4.14E+00	5.34E+00
Total PCDD	2.39E+01	2.26E+01	1.22E+01	1.96E+01
FURANS				
2378 TCDF	NR	NR	NR	NR
Other TCDF	3.91E+01	3.80E+01	2.11E+01	3.28E+01
Penta-CDF	1.27E+01	1.10E+01	6.41E+00	1.00E+01
Hexa-CDF	ND(7.52E-01)	ND(6.23E-01)	3.09E-01	1.03E-01
Hepta-CDF	4.95E-01	6.67E-01	3.47E-01	5.03E-01
Octa-CDF	ND(4.50E-01)	3.11E-01	ND(1.74E-01)	1.04E-01
Total PCDF	5.22E+01	5.00E+01	2.82E+01	4.35E+01

NOTE: Isomer concentrations shown are corrected to 3% oxygen.
NR = not reported by Troika.
ND = not detected (detection limit in parentheses).
ng = 1.0E-09g
6000 operating hours per year

TABLE A.2.2. SITE 2 (ISW-A)/OUTLET
DIOXIN/FURAN EMISSION CONCENTRATIONS
(Values corrected to 3% O_2)

Dioxin/Furan Isomer	Isomer Concentration in Flue Gas (ng/dscm @ 3% oxygen)			
	Run 01	Run 03	Run 04	Avg.
DIOXINS				
2378 TCDD	2.17E+00	4.89E+00	6.52E+00	4.53E+00
Other TCDD	3.58E+01	8.67E+01	1.08E+02	7.69E+01
Penta-CDD	5.43E+01	1.08E+02	1.47E+02	1.03E+02
Hexa-CDD	1.06E+02	1.31E+02	1.98E+02	1.45E+02
Hepta-CDD	1.27E+02	1.67E+02	4.07E+02	2.34E+02
Octa-CDD	5.21E+01	5.87E+01	7.30E+01	6.13E+01
Total PCDD	3.78E+02	5.57E+02	9.40E+02	6.25E+02
FURANS				
2378 TCDF	1.19E+01	2.17E+01	2.87E+01	2.08E+01
Other TCDF	3.66E+02	4.84E+02	8.74E+02	5.74E+02
Penta-CDF	3.81E+02	4.76E+02	9.64E+02	6.07E+02
Hexa-CDF	6.08E+02	4.40E+02	9.08E+02	6.52E+02
Hepta-CDF	3.35E+02	2.98E+02	7.78E+02	4.71E+02
Octa-CDF	5.75E+01	6.08E+01	7.95E+01	6.60E+01
Total PCDF	1.76E+03	1.78E+03	3.63E+03	2.39E+03

NOTE: Isomer concentrations shown are corrected to 3% oxygen.

ND = not detected (detection limit in parentheses).
ng = 1.0E-09g
2200 operating hours per year

TABLE A.2.3. SITE 3 (SSI-B)/OUTLET
DIOXIN/FURAN EMISSION CONCENTRATIONS
(Values corrected to 3% O_2)

Dioxin/Furan Isomer	Isomer Concentration in Flue Gas (ng/dscm @ 3% oxygen) Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	ND(6.59E-02)	ND(2.01E-01)	ND(3.90E-02)	.00E+00
Other TCDD	1.10E+00	ND(2.01E-01)	9.74E-02	3.99E-01
Penta-CDD	ND(1.10E-01)	ND(1.51E-01)	ND(1.95E-01)	.00E+00
Hexa-CDD	ND(1.05E+00)	ND(3.43E-01)	ND(2.92E-02)	.00E+00
Hepta-CDD	6.59E-01	ND(2.26E-01)	ND(1.36E-01)	2.20E-01
Octa-CDD	1.76E+00	5.86E-01	5.84E-01	9.76E-01
Total PCDD	3.52E+00	5.86E-01	6.82E-01	1.59E+00
FURANS				
2378 TCDF	4.18E+00	8.36E-01	1.36E+00	2.13E+00
Other TCDF	4.29E+01	5.10E+00	9.06E+00	1.90E+01
Penta-CDF	1.19E+01	ND(1.51E-01)	2.44E+00	4.77E+00
Hexa-CDF	4.84E+00	ND(1.92E-01)	ND(7.21E-01)	1.61E+00
Hepta-CDF	ND(1.36E+00)	ND(2.43E-01)	ND(6.82E-02)	.00E+00
Octa-CDF	2.20E-01	ND(4.18E-02)	ND(5.84E-02)	7.33E-02
Total PCDF	6.40E+01	5.94E+00	1.29E+01	2.76E+01

NOTE: Isomer concentrations shown are corrected to 3% oxygen.

ND = not detected (detection limit in parentheses).
ng = 1.0E-09g
8760 operating hours per year

TABLE A.2.4a. SITE 4 (BLB-A)/INLET
DIOXIN/FURAN EMISSION CONCENTRATIONS
(Values corrected to 3% O_2)

Dioxin/Furan Isomer	Isomer Concentration in Flue Gas (ng/dscm @ 3% oxygen)			
	Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	ND(2.18E-02)	ND(2.23E-02)	ND(8.40E-02)	.00E+00
Other TCDD	ND(2.18E-02)	2.23E-02	ND(8.40E-02)	7.44E-03
Penta-CDD	ND(8.46E-02)	ND(2.68E-02)	ND(1.12E-01)	.00E+00
Hexa-CDD	1.37E-01	8.93E-02	ND(4.39E-01)	7.53E-02
Hepta-CDD	3.28E-01	2.23E-01	6.54E-01	4.01E-01
Octa-CDD	9.01E-01	7.14E-01	2.29E+00	1.30E+00
Total PCDD	1.37E+00	1.05E+00	2.94E+00	1.79E+00
FURANS				
2378 TCDF	ND(1.64E-02)	ND(8.93E-02)	ND(1.87E-01)	.00E+00
Other TCDF	2.73E-01	2.23E-01	4.67E-01	3.21E-01
Penta-CDF	3.55E-01	2.68E-01	ND(6.91E-01)	2.08E-01
Hexa-CDF	4.92E-01	4.46E-01	8.87E-01	6.08E-01
Hepta-CDF	2.73E-01	1.34E-01	4.20E-01	2.76E-01
Octa-CDF	8.19E-02	8.93E-02	ND(2.94E-01)	5.71E-02
Total PCDF	1.47E+00	1.16E+00	1.77E+00	1.47E+00

NOTE: Isomer concentrations shown are corrected to 3% oxygen.

ND = not detected (detection limit in parentheses).
ng = 1.0E-09g
8760 operating hours per year

TABLE A.2.4b. SITE 4 (BLB-A)/OUTLET DIOXIN/FURAN EMISSION CONCENTRATIONS (Values corrected to 3% O_2)

Dioxin/Furan Isomer	Isomer Concentration in Flue Gas (ng/dscm @ 3% oxygen)			
	Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	ND(6.75E-02)	ND(1.97E-02)	ND(2.03E-02)	.00E+00
Other TCDD	ND(6.75E-02)	5.91E-02	ND(2.03E-02)	1.97E-02
Penta-CDD	ND(2.83E-02)	ND(2.37E-02)	ND(4.05E-02)	.00E+00
Hexa-CDD	1.74E-01	ND(6.31E-02)	ND(4.42E-02)	5.80E-02
Hepta-CDD	3.48E-01	9.86E-02	9.21E-02	1.80E-01
Octa-CDD	8.05E-01	4.34E-01	2.40E-01	4.93E-01
Total PCDD	1.33E+00	5.91E-01	3.32E-01	7.50E-01
FURANS				
2378 TCDF	ND(8.70E-03)	ND(3.94E-02)	ND(1.84E-02)	.00E+00
Other TCDF	3.70E-01	5.91E-02	3.68E-02	1.55E-01
Penta-CDF	1.74E-01	ND(4.53E-02)	ND(2.40E-02)	5.80E-02
Hexa-CDF	1.52E-01	5.91E-02	ND(9.40E-02)	7.05E-02
Hepta-CDF	2.18E-01	1.97E-01	5.53E-02	1.57E-01
Octa-CDF	8.70E-02	2.96E-01	1.84E-02	1.34E-01
Total PCDF	1.00E+00	6.11E-01	1.11E-01	5.74E-01

NOTE: Isomer concentrations shown are corrected to 3% oxygen.

ND = not detected (detection limit in parentheses).
ng = 1.0E-09g
8760 operating hours per year

TABLE A.2.5a. SITE 5 (BLB-B)/INLET
DIOXIN/FURAN EMISSION CONCENTRATIONS
(Values corrected to 3% O_2)

Dioxin/Furan Isomer	Isomer Concentration in Flue Gas (ng/dscm @ 3% oxygen) Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	ND(4.15E-02)	ND(6.90E-02)	ND(2.77E-02)	.00E+00
Other TCDD	ND(4.15E-02)	ND(6.90E-02)	ND(2.77E-02)	.00E+00
Penta-CDD	ND(4.15E-02)	ND(7.67E-03)	ND(9.89E-02)	.00E+00
Hexa-CDD	ND(4.15E-02)	ND(9.59E-02)	2.37E-01	7.91E-02
Hepta-CDD	1.84E-01	8.05E-01	7.75E+00	2.91E+00
Octa-CDD	7.37E-01	2.57E+00	3.90E+01	1.41E+01
Total PCDD	9.22E-01	3.37E+00	4.70E+01	1.71E+01
FURANS				
2378 TCDF	4.61E-02	ND(6.90E-02)	7.91E-02	4.17E-02
Other TCDF	4.61E-02	ND(6.90E-02)	5.14E-01	1.87E-01
Penta-CDF	ND(1.11E-01)	ND(3.83E-02)	ND(9.89E-02)	.00E+00
Hexa-CDF	9.22E-02	1.15E-01	2.77E-01	1.61E-01
Hepta-CDF	4.61E-02	3.83E-01	7.12E-01	3.81E-01
Octa-CDF	4.61E-02	2.68E-01	5.14E-01	2.76E-01
Total PCDF	2.77E-01	7.67E-01	2.10E+00	1.05E+00

NOTE: Isomer concentrations shown are corrected to 3% oxygen.

ND = not detected (detection limit in parentheses).
ng = 1.0E-09g
8760 operating hours per year

TABLE A.2.5b. SITE 5 (BLB-B)/OUTLET
DIOXIN/FURAN EMISSION CONCENTRATIONS
(Values corrected to 3% O_2)

Dioxin/Furan Isomer	Isomer Concentration in Flue Gas (ng/dscm @ 3% oxygen)			
	Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	ND(3.59E-02)	ND(1.36E-02)	ND(2.85E-02)	.00E+00
Other TCDD	ND(3.59E-02)	ND(1.36E-02)	ND(2.85E-02)	.00E+00
Penta-CDD	ND(5.38E-02)	ND(3.80E-02)	ND(1.56E-01)	.00E+00
Hexa-CDD	2.24E-01	ND(9.77E-02)	7.78E-02	1.01E-01
Hepta-CDD	4.03E-01	1.90E-01	1.82E-01	2.58E-01
Octa-CDD	1.25E+00	6.24E-01	6.23E-01	8.34E-01
Total PCDD	1.88E+00	8.14E-01	8.82E-01	1.19E+00
FURANS				
2378 TCDF	ND(4.48E-02)	ND(4.62E-02)	2.59E-02	8.65E-03
Other TCDF	3.14E-01	ND(4.62E-02)	7.78E-02	1.31E-01
Penta-CDF	ND(3.27E-01)	ND(3.80E-02)	ND(1.56E-01)	.00E+00
Hexa-CDF	8.51E-01	ND(1.57E-01)	1.56E-01	3.36E-01
Hepta-CDF	3.14E-01	8.14E-02	1.04E-01	1.66E-01
Octa-CDF	8.96E-02	5.43E-02	5.19E-02	6.53E-02
Total PCDF	1.57E+00	1.36E-01	4.15E-01	7.06E-01

NOTE: Isomer concentrations shown are corrected to 3% oxygen.

ND = not detected (detection limit in parentheses).
ng = 1.0E-09g
8760 operating hours per year

TABLE A.2.6a SITE 6 (WRI-A)/OUTLET
(Wire only)
DIOXIN/FURAN EMISSION CONCENTRATIONS
(Values corrected to 3% O_2)

Dioxin/Furan Isomer	Isomer Concentration in Flue Gas (ng/dscm @ 3% oxygen) Run 01	Run 02	Run 06	Avg.
DIOXINS				
2378 TCDD	NR	NR	1.38E-01	1.38E-01
Other TCDD	5.59E-01	NR	1.84E+00	1.20E+00
Penta-CDD	NR	NR	3.04E+00	3.04E+00
Hexa-CDD	3.36E+00	NR	1.31E+01	8.23E+00
Hepta-CDD	3.45E+01	2.24E+01	2.07E+02	8.79E+01
Octa-CDD	1.67E+01	1.29E+01	1.87E+02	7.24E+01
Total PCDD	5.52E+01	3.53E+01	4.12E+02	1.73E+02
FURANS				
2378 TCDF	NR	NR	5.53E-01	5.53E-01
Other TCDF	4.22E+00	1.00E+01	2.42E+01	1.28E+01
Penta-CDF	5.72E+00	NR	3.96E+01	2.27E+01
Hexa-CDF	1.33E+01	3.31E+00	9.02E+01	3.56E+01
Hepta-CDF	5.14E+01	6.37E+01	3.78E+02	1.64E+02
Octa-CDF	2.93E+01	3.04E+01	1.48E+02	6.93E+01
Total PCDF	1.04E+02	1.07E+02	6.80E+02	3.05E+02

NOTE: Isomer concentrations shown are corrected to 3% oxygen.
NR = not reported by Troika.
ND = not detected (detection limit in parentheses).
ng = 1.0E-09g
2080 operating hours per year

NOTE: Several recoveries for the MM5 train samples did not meet the quality assurance requirements for all four labelled compounds. Problems with method efficiency resulted from contamination present in the sample extracts and corresponding difficulties in achieving acceptable chromatographic separations. The reported analytical results may actually represent lower bounds on the true values. See Section 7.3.1 for more details.

TABLE A.2.6b SITE 6 (WRI-A)/OUTLET
(Wire and Transformers)
DIOXIN/FURAN EMISSION CONCENTRATIONS
(Values corrected to 3% O_2)

Dioxin/Furan Isomer	Isomer Concentration in Flue Gas (ng/dscm @ 3% oxygen) Run 03	Run 04	Run 05	Avg.
DIOXINS				
2378 TCDD	5.83E-02	NR	1.94E-01	1.26E-01
Other TCDD	2.62E-01	1.68E+00	2.57E+00	1.50E+00
Penta-CDD	4.87E+00	NR	5.43E+00	5.15E+00
Hexa-CDD	5.64E+01	NR	9.26E+00	3.28E+01
Hepta-CDD	3.89E+02	7.85E+01	3.48E+01	1.67E+02
Octa-CDD	1.38E+03	7.95E+01	3.10E+01	4.98E+02
Total PCDD	1.83E+03	1.60E+02	8.32E+01	7.05E+02
FURANS				
2378 TCDF	4.66E-01	NR	1.36E+00	9.13E-01
Other TCDF	2.95E+01	6.86E+01	3.61E+01	4.48E+01
Penta-CDF	6.22E+01	NR	2.17E+01	4.20E+01
Hexa-CDF	2.01E+02	4.79E+01	3.52E+01	9.48E+01
Hepta-CDF	4.40E+02	3.35E+02	1.04E+02	2.93E+02
Octa-CDF	9.21E+02	1.73E+02	7.75E+01	3.90E+02
Total PCDF	1.65E+03	6.25E+02	2.76E+02	8.66E+02

NOTE: Isomer concentrations shown are corrected to 3% oxygen.
NR = not reported by Troika.
ND = not detected (detection limit in parentheses).
ng = 1.0E-09g
2080 operating hours per year

NOTE: Several recoveries for the MM5 train samples did not meet the quality assurance requirements for all four labelled compounds. Problems with method efficiency resulted from contamination present in the sample extracts and corresponding difficulties in achieving acceptable chromatographic separations. The reported analytical results may actually represent lower bounds on the true values. See Section 7.3.1 for more details.

TABLE A.2.7a. SITE 7 (WFB-A)/INLET
DIOXIN/FURAN EMISSION CONCENTRATIONS
(Values corrected to 3% O_2)

Dioxin/Furan Isomer	Isomer Concentration in Flue Gas (ng/dscm @ 3% oxygen) Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	NR	9.39E-01	8.06E-01	8.73E-01
Other TCDD	1.12E+01	2.21E+01	3.13E+01	2.15E+01
Penta-CDD	NR	2.60E+01	2.95E+01	2.78E+01
Hexa-CDD	1.15E+01	2.59E+01	2.99E+01	2.25E+01
Hepta-CDD	2.12E+01	2.06E+01	1.68E+01	1.95E+01
Octa-CDD	2.05E+01	4.98E+00	4.40E+00	9.96E+00
Total PCDD	6.44E+01	1.01E+02	1.13E+02	1.02E+02
FURANS				
2378 TCDF	NR	5.85E+00	5.86E+00	5.86E+00
Other TCDF	6.97E+01	1.10E+02	1.20E+02	1.00E+02
Penta-CDF	1.10E+01	4.19E+01	4.26E+01	3.18E+01
Hexa-CDF	7.60E+00	1.50E+01	1.73E+01	1.33E+01
Hepta-CDF	3.07E+00	6.43E+00	5.64E+00	5.05E+00
Octa-CDF	ND(7.41E+00)	6.50E-01	5.86E-01	4.12E-01
Total PCDF	9.13E+01	1.80E+02	1.92E+02	1.56E+02

NOTE: Isomer concentrations shown are corrected to 3% oxygen.
NR = not reported by Troika.
ND = not detected (detection limit in parentheses).
ng = 1.0E-09g
8760 operating hours per year

TABLE A.2.7b. SITE 7 (WFB-A)/OUTLET
DIOXIN/FURAN EMISSION CONCENTRATIONS
(Values corrected to 3% O_2)

Dioxin/Furan Isomer	Isomer Concentration in Flue Gas (ng/dscm @ 3% oxygen) Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	2.12E-01	2.73E-01	3.52E-01	2.79E-01
Other TCDD	4.90E+01	6.44E+01	2.84E+01	4.73E+01
Penta-CDD	6.24E+01	5.89E+01	2.28E+01	4.80E+01
Hexa-CDD	6.42E+01	6.01E+01	2.34E+01	4.92E+01
Hepta-CDD	3.50E+01	4.54E+01	3.54E+01	3.86E+01
Octa-CDD	9.96E+00	1.15E+01	1.21E+01	1.12E+01
Total PCDD	2.21E+02	2.40E+02	1.22E+02	1.95E+02
FURANS				
2378 TCDF	1.38E+00	1.82E+00	2.11E+00	1.77E+00
Other TCDF	3.49E+01	5.22E+01	2.51E+01	3.74E+01
Penta-CDF	2.40E+01	3.08E+01	1.50E+01	2.33E+01
Hexa-CDF	1.51E+01	2.07E+01	4.10E+00	1.33E+01
Hepta-CDF	6.36E+00	9.51E+00	3.75E+00	6.54E+00
Octa-CDF	1.27E+00	7.74E-01	7.03E-01	9.16E-01
Total PCDF	8.29E+01	1.16E+02	5.08E+01	8.32E+01

NOTE: Isomer concentrations shown are corrected to 3% oxygen.

ND = not detected (detection limit in parentheses).
ng = 1.0E-09g
8760 operating hours per year

TABLE A.2.8a. SITE 8 (BLB-C)/INLET
DIOXIN/FURAN EMISSION CONCENTRATIONS
(Values corrected to 3% O_2)

Dioxin/Furan Isomer	Isomer Concentration in Flue Gas (ng/dscm @ 3% oxygen)			
	Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	ND(.00E+00)	ND(.00E+00)	ND(.00E+00)	.00E+00
Other TCDD	1.76E+00	7.62E-01	7.80E-01	1.10E+00
Penta-CDD	2.23E+00	1.13E+00	9.10E-01	1.42E+00
Hexa-CDD	3.45E+00	2.40E+00	2.21E+00	2.68E+00
Hepta-CDD	3.04E+00	1.85E+00	1.56E+00	2.15E+00
Octa-CDD	2.03E+00	1.52E+00	1.37E+00	1.64E+00
Total PCDD	1.25E+01	7.66E+00	6.83E+00	9.00E+00
FURANS				
2378 TCDF	ND(.00E+00)	ND(.00E+00)	ND(.00E+00)	.00E+00
Other TCDF	1.34E+01	1.49E+00	1.43E+00	5.43E+00
Penta-CDF	1.28E+01	8.71E-01	ND(8.45E-01)	4.55E+00
Hexa-CDF	9.46E+00	1.20E+00	1.04E+00	3.90E+00
Hepta-CDF	2.50E+00	4.36E-01	3.25E-01	1.09E+00
Octa-CDF	3.38E-01	2.18E-01	ND(1.95E-01)	1.85E-01
Total PCDF	3.84E+01	4.21E+00	2.80E+00	1.51E+01

NOTE: Isomer concentrations shown are corrected to 3% oxygen.

ND = not detected (detection limit in parentheses).
ng = 1.0E-09g
8760 operating hours per year

TABLE A.2.8b. SITE 8 (BLB-C)/OUTLET DIOXIN/FURAN EMISSION CONCENTRATIONS (Values corrected to 3% O_2)

Dioxin/Furan Isomer	Isomer Concentration in Flue Gas (ng/dscm @ 3% oxygen)			
	Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	ND(2.39E-02)	ND(3.90E-03)	ND(6.11E-03)	.00E+00
Other TCDD	1.20E-01	1.07E-01	1.53E-01	1.27E-01
Penta-CDD	ND(5.98E-02)	2.15E-01	2.44E-01	1.53E-01
Hexa-CDD	1.79E-01	4.10E-01	5.81E-01	3.90E-01
Hepta-CDD	2.99E-01	1.19E+00	1.16E+00	8.84E-01
Octa-CDD	7.18E-01	2.34E+00	1.10E+00	1.39E+00
Total PCDD	1.32E+00	4.27E+00	3.24E+00	2.94E+00
FURANS				
2378 TCDF	ND(3.59E-02)	1.56E-02	ND(6.11E-03)	5.21E-03
Other TCDF	2.99E-01	2.58E-01	8.25E-01	4.61E-01
Penta-CDF	ND(1.20E-01)	2.15E-01	1.16E+00	4.59E-01
Hexa-CDF	2.99E-01	2.25E-01	1.25E+00	5.92E-01
Hepta-CDF	2.39E-01	3.32E-01	9.17E-01	4.96E-01
Octa-CDF	1.20E-01	3.90E-02	1.22E-01	9.36E-02
Total PCDF	9.57E-01	1.08E+00	4.28E+00	2.11E+00

NOTE: Isomer concentrations shown are corrected to 3% oxygen.

ND = not detected (detection limit in parentheses).
ng = 1.0E-09g
8760 operating hours per year

TABLE A.2.9a. SITE 9 (CRF-A)/INLET
DIOXIN/FURAN EMISSION CONCENTRATIONS
(Values corrected to 3% O_2)

Dioxin/Furan Isomer	Isomer Concentration in Flue Gas (ng/dscm @ 3% oxygen) Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	6.86E-02	6.12E-02	1.44E-01	9.14E-02
Other TCDD	1.23E+00	1.07E+00	5.02E+00	2.44E+00
Penta-CDD	2.71E+00	5.82E-01	4.08E+00	2.46E+00
Hexa-CDD	8.10E+00	3.58E+00	5.92E+00	5.87E+00
Hepta-CDD	1.07E+01	7.75E+00	6.46E+00	8.29E+00
Octa-CDD	1.23E+01	1.32E+01	3.46E+00	9.65E+00
Total PCDD	3.51E+01	2.62E+01	2.51E+01	2.88E+01
FURANS				
2378 TCDF	1.20E+00	1.44E+00	1.52E+00	1.39E+00
Other TCDF	1.63E+01	2.14E+01	2.28E+01	2.02E+01
Penta-CDF	1.18E+01	1.16E+01	2.04E+01	1.46E+01
Hexa-CDF	1.40E+01	1.52E+01	1.85E+01	1.59E+01
Hepta-CDF	9.78E+00	1.37E+01	1.46E+01	1.27E+01
Octa-CDF	4.49E+00	6.03E+00	5.63E+00	5.39E+00
Total PCDF	5.75E+01	6.93E+01	8.34E+01	7.01E+01

NOTE: Isomer concentrations shown are corrected to 3% oxygen.

ND = not detected (detection limit in parentheses).
ng = 1.0E-09g
8760 operating hours per year

TABLE A.2.9b. SITE 9 (CRF-A)/OUTLET
DIOXIN/FURAN EMISSION CONCENTRATIONS
(Values corrected to 3% O_2)

Dioxin/Furan Isomer	Isomer Concentration in Flue Gas (ng/dscm @ 3% oxygen)			
	Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	ND(4.61E-01)	ND(1.31E-01)	ND(1.30E-01)	.00E+00
Other TCDD	1.52E+00	ND(1.96E-01)	1.95E-01	5.70E-01
Penta-CDD	9.88E-01	3.27E-01	ND(3.25E-01)	4.38E-01
Hexa-CDD	1.58E+00	7.84E-01	5.84E-01	9.83E-01
Hepta-CDD	1.19E+00	8.49E-01	6.49E-01	8.95E-01
Octa-CDD	1.05E+00	7.19E-01	6.49E-01	8.07E-01
Total PCDD	6.32E+00	2.68E+00	2.08E+00	3.69E+00
FURANS				
2378 TCDF	ND(3.95E-01)	ND(3.92E-01)	ND(2.60E-01)	.00E+00
Other TCDF	1.38E+00	1.31E+00	9.09E-01	1.20E+00
Penta-CDF	3.95E-01	7.19E-01	ND(3.25E-01)	3.71E-01
Hexa-CDF	7.25E-01	5.23E-01	5.19E-01	5.89E-01
Hepta-CDF	8.56E-01	5.23E-01	4.54E-01	6.11E-01
Octa-CDF	5.93E-01	3.27E-01	7.14E-01	5.44E-01
Total PCDF	3.95E+00	3.40E+00	2.60E+00	3.32E+00

NOTE: Isomer concentrations shown are corrected to 3% oxygen.

ND = not detected (detection limit in parentheses).
ng = 1.0E-09g
8760 operating hours per year

TABLE A.2.10. SITE 10 (MET-A)/OUTLET
DIOXIN/FURAN EMISSION CONCENTRATIONS
(Values corrected to 3% O_2)

Dioxin/Furan Isomer	Isomer Concentration in Flue Gas (ng/dscm @ 3% oxygen)			
	Run 02	Run 03	Run 04	Avg.
DIOXINS				
2378 TCDD	3.95E+02	1.70E+02	1.30E+02	2.32E+02
Other TCDD	7.93E+02	1.40E+03	1.22E+03	1.14E+03
Penta-CDD	1.41E+03	2.33E+03	1.68E+03	1.81E+03
Hexa-CDD	3.27E+03	2.15E+03	1.52E+03	2.32E+03
Hepta-CDD	2.46E+03	5.86E+03	3.34E+03	3.89E+03
Octa-CDD	1.47E+03	3.70E+03	2.39E+03	2.52E+03
Total PCDD	9.80E+03	1.56E+04	1.03E+04	1.19E+04
FURANS				
2378 TCDF	4.18E+03	5.06E+03	5.97E+03	5.07E+03
Other TCDF	1.41E+04	1.78E+04	2.99E+04	2.06E+04
Penta-CDF	1.26E+04	1.85E+04	1.72E+04	1.61E+04
Hexa-CDF	1.15E+04	6.08E+03	5.81E+03	7.79E+03
Hepta-CDF	4.06E+03	1.06E+04	4.44E+03	6.38E+03
Octa-CDF	2.76E+03	7.20E+03	4.15E+03	4.70E+03
Total PCDF	4.92E+04	6.53E+04	6.74E+04	6.07E+04

NOTE: Isomer concentrations shown are corrected to 3% oxygen.

ND = not detected (detection limit in parentheses).
ng = 1.0E-09g
8160 operating hours per year

NOTE: Surrogate recoveries could not be determined for Run 02 and 04 dioxin/furan samples because of the relatively large quantities of native CDD and CDF species present in the samples. The reported analytical results may actually represent lower bounds on the true values. See Section 7.3.1 for more details.

TABLE A.2.11a. SITE 11 (DBR-A)/INLET
DIOXIN/FURAN EMISSION CONCENTRATIONS
(Values corrected to 3% O_2)

Dioxin/Furan Isomer	Isomer Concentration in Flue Gas (ng/dscm @ 3% oxygen) Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	1.76E+01	1.84E+01	1.32E+01	1.64E+01
Other TCDD	6.07E+01	6.30E+01	1.09E+02	7.76E+01
Penta-CDD	9.19E+01	5.49E+01	1.65E+02	1.04E+02
Hexa-CDD	8.94E+01	3.57E+01	2.84E+02	1.36E+02
Hepta-CDD	5.03E+02	1.48E+01	2.81E+02	2.66E+02
Octa-CDD	1.87E+02	1.24E+01	6.15E+01	8.69E+01
Total PCDD	9.49E+02	1.99E+02	9.14E+02	6.87E+02
FURANS				
2378 TCDF	5.09E+01	6.98E+01	6.68E+01	6.25E+01
Other TCDF	6.85E+02	6.92E+02	1.41E+03	9.30E+02
Penta-CDF	5.95E+02	3.51E+02	8.84E+02	6.10E+02
Hexa-CDF	1.53E+02	6.47E+01	4.85E+02	2.34E+02
Hepta-CDF	4.66E+02	2.70E+01	2.74E+02	2.56E+02
Octa-CDF	1.50E+02	6.22E+00	6.49E+01	7.38E+01
Total PCDF	2.10E+03	1.21E+03	3.19E+03	2.17E+03

NOTE: Isomer concentrations shown are corrected to 3% oxygen.

ND = not detected (detection limit in parentheses).
ng = 1.0E-09g
1536 operating hours per year

NOTE: Several recoveries for the MM5 train samples did not meet the quality assurance requirements for all four labelled compounds. Problems with method efficiency resulted from contamination present in the sample extracts and corresponding difficulties in achieving acceptable chromatographic separations. The reported analytical results may actually represent lower bounds on the true values. See Section 7.3.1 for more details.

TABLE A.2.11b. SITE 11 (DBR-A)/OUTLET
DIOXIN/FURAN EMISSION CONCENTRATIONS
(Values corrected to 3% O_2)

Dioxin/Furan Isomer	Isomer Concentration in Flue Gas (ng/dscm @ 3% oxygen) Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	6.59E-02	2.79E-02	6.10E-02	5.16E-02
Other TCDD	1.58E+00	8.80E-01	1.10E+00	1.19E+00
Penta-CDD	1.45E+00	2.79E-01	4.27E-01	7.19E-01
Hexa-CDD	1.32E+00	4.19E-01	6.41E-01	7.93E-01
Hepta-CDD	2.37E+00	7.68E-01	7.94E-01	1.31E+00
Octa-CDD	1.32E+00	7.68E-01	6.71E-01	9.19E-01
Total PCDD	8.11E+00	3.14E+00	3.69E+00	4.98E+00
FURANS				
2378 TCDF	1.58E+00	5.59E-01	5.49E-01	8.97E-01
Other TCDF	1.67E+01	1.51E+01	1.12E+01	1.43E+01
Penta-CDF	9.82E+00	4.54E+00	4.24E+00	6.20E+00
Hexa-CDF	4.88E+00	2.23E+00	1.86E+00	2.99E+00
Hepta-CDF	3.36E+00	1.47E+00	1.22E+00	2.02E+00
Octa-CDF	9.23E-01	4.19E-01	3.05E-01	5.49E-01
Total PCDF	3.73E+01	2.43E+01	1.94E+01	2.70E+01

NOTE: Isomer concentrations shown are corrected to 3% oxygen.

ND = not detected (detection limit in parentheses).
ng = 1.0E-09g
1536 operating hours per year

TABLE A.2.12a. SITE 12 (SSI-C)/INLET
DIOXIN/FURAN EMISSION CONCENTRATIONS
(Values corrected to 3% O_2)

Dioxin/Furan Isomer	Isomer Concentration in Flue Gas (ng/dscm @ 3% oxygen)			
	Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	NR	NR	NR	NR
Other TCDD	NR	3.98E+00	1.29E+01	8.44E+00
Penta-CDD	NR	ND(2.25E+00)	7.37E-01	3.69E-01
Hexa-CDD	NR	8.14E+00	1.01E+01	9.12E+00
Hepta-CDD	NR	6.16E+01	3.00E+01	4.58E+01
Octa-CDD	NR	6.76E+01	3.35E+01	5.06E+01
Total PCDD	NR	1.41E+02	8.72E+01	1.14E+02
FURANS				
2378 TCDF	NR	4.71E+01	1.20E+02	8.36E+01
Other TCDF	NR	1.14E+02	1.79E+02	1.47E+02
Penta-CDF	NR	1.03E+02	1.61E+02	1.32E+02
Hexa-CDF	NR	1.17E+01	1.51E+01	1.34E+01
Hepta-CDF	NR	1.12E+02	1.76E+01	6.48E+01
Octa-CDF	NR	1.12E+02	2.02E+01	6.61E+01
Total PCDF	NR	5.00E+02	5.13E+02	5.07E+02

NOTE: Isomer concentrations shown are corrected to 3% oxygen.
NR = not reported by Troika.
ND = not detected (detection limit in parentheses).
ng = 1.0E-09g
8760 operating hours per year

NOTE: Several recoveries for the MM5 train samples did not meet the quality assurance requirements for all four labelled compounds. Problems with method efficiency resulted from contamination present in the sample extracts and corresponding difficulties in achieving acceptable chromatographic separations. The reported analytical results may actually represent lower bounds on the true values. See Section 7.3.1 for more details.

TABLE A.2.12b. SITE 12 (SSI-C)/OUTLET DIOXIN/FURAN EMISSION CONCENTRATIONS (Values corrected to 3% O_2)

Dioxin/Furan Isomer	Isomer Concentration in Flue Gas (ng/dscm @ 3% oxygen)			
	Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	1.55E-01	1.30E-01	1.42E-01	1.42E-01
Other TCDD	8.37E+00	8.75E+00	7.23E+00	8.12E+00
Penta-CDD	8.86E-01	1.11E+00	1.21E+00	1.07E+00
Hexa-CDD	5.87E+00	8.79E+00	6.31E+00	6.99E+00
Hepta-CDD	8.64E+00	4.09E+01	1.39E+01	2.11E+01
Octa-CDD	7.09E+00	2.76E+01	1.11E+01	1.52E+01
Total PCDD	3.10E+01	8.72E+01	3.98E+01	5.27E+01
FURANS				
2378 TCDF	6.76E+01	5.16E+01	4.38E+01	5.43E+01
Other TCDF	1.50E+02	1.66E+02	1.33E+02	1.50E+02
Penta-CDF	1.12E+02	1.08E+02	9.56E+01	1.05E+02
Hexa-CDF	1.85E+01	4.83E+01	2.93E+01	3.20E+01
Hepta-CDF	8.64E+00	1.32E+02	3.91E+01	6.00E+01
Octa-CDF	3.99E+00	1.03E+02	2.88E+01	4.52E+01
Total PCDF	3.60E+02	6.08E+02	3.70E+02	4.46E+02

NOTE: Isomer concentrations shown are corrected to 3% oxygen.

ND = not detected (detection limit in parentheses).
ng = 1.0E-09g
8760 operating hours per year

APPENDIX A.3

Summary of PCDD/PCDF Emissions Per Unit of Feed
(ug emitted per kg of feed)

TABLE A.3.1. SITE 1 (SSI-A)/OUTLET
DIOXIN/FURAN EMISSION FACTORS
(Dry Solids Feed Rate Basis)

Dioxin/Furan Isomer	Dioxin/Furan Emission Factors (ug/kg)			
	Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	2.09E-04	3.09E-04	1.49E-04	2.22E-04
Other TCDD	7.00E-02	5.48E-02	4.55E-02	5.68E-02
Penta-CDD	8.71E-04	1.42E-03	ND(1.01E-03)	7.64E-04
Hexa-CDD	ND(1.67E-03)	4.22E-03	3.63E-03	2.62E-03
Hepta-CDD	1.56E-02	1.03E-02	1.37E-02	1.32E-02
Octa-CDD	3.71E-02	1.86E-02	3.23E-02	2.94E-02
Total PCDD	1.24E-01	8.97E-02	9.53E-02	1.03E-01
FURANS				
2378 TCDF	NR	NR	NR	NR
Other TCDF	2.02E-01	1.51E-01	1.65E-01	1.73E-01
Penta-CDF	6.55E-02	4.35E-02	5.01E-02	5.30E-02
Hexa-CDF	ND(3.89E-03)	ND(2.47E-03)	2.41E-03	8.03E-04
Hepta-CDF	2.56E-03	2.65E-03	2.71E-03	2.64E-03
Octa-CDF	ND(2.33E-03)	1.24E-03	ND(1.36E-03)	4.12E-04
Total PCDF	2.70E-01	1.99E-01	2.20E-01	2.30E-01

NR = not reported by Troika.
ND = not detected (detection limit in parentheses).
ug = 1.0E-06g
6000 operating hours per year

TABLE A.3.2. SITE 2 (ISW-A)/OUTLET
DIOXIN/FURAN EMISSION FACTORS
(Total Feed Rate Basis)

Dioxin/Furan Isomer	Dioxin/Furan Emission Factors (ug/kg)			
	Run 01	Run 03	Run 04	Avg.
DIOXINS				
2378 TCDD	5.69E-03	2.12E-02	1.18E-02	1.29E-02
Other TCDD	9.39E-02	3.75E-01	1.97E-01	2.22E-01
Penta-CDD	1.42E-01	4.69E-01	2.68E-01	2.93E-01
Hexa-CDD	2.79E-01	5.66E-01	3.60E-01	4.01E-01
Hepta-CDD	3.33E-01	7.23E-01	7.39E-01	5.98E-01
Octa-CDD	1.37E-01	2.54E-01	1.33E-01	1.74E-01
Total PCDD	9.90E-01	2.41E+00	1.71E+00	1.70E+00
FURANS				
2378 TCDF	3.13E-02	9.38E-02	5.21E-02	5.91E-02
Other TCDF	9.58E-01	2.09E+00	1.59E+00	1.55E+00
Penta-CDF	9.98E-01	2.06E+00	1.75E+00	1.60E+00
Hexa-CDF	1.59E+00	1.90E+00	1.65E+00	1.71E+00
Hepta-CDF	8.79E-01	1.29E+00	1.41E+00	1.19E+00
Octa-CDF	1.51E-01	2.63E-01	1.45E-01	1.86E-01
Total PCDF	4.61E+00	7.70E+00	6.60E+00	6.30E+00

ND = not detected (detection limit in parentheses).
ug = 1.0E-06g
2200 operating hours per year

TABLE A.3.3. SITE 3 (SSI-B)/OUTLET
DIOXIN/FURAN EMISSION FACTORS
(Dry Solids Feed Rate Basis)

Dioxin/Furan Isomer	Dioxin/Furan Emission Factors (ug/kg)			
	Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	ND(1.77E-04)	ND(6.59E-04)	ND(1.75E-04)	.00E+00
Other TCDD	2.96E-03	ND(6.59E-04)	4.38E-04	1.13E-03
Penta-CDD	ND(2.96E-04)	ND(4.94E-04)	ND(8.77E-04)	.00E+00
Hexa-CDD	ND(2.84E-03)	ND(1.12E-03)	ND(1.31E-04)	.00E+00
Hepta-CDD	1.77E-03	ND(7.41E-04)	ND(6.14E-04)	5.92E-04
Octa-CDD	4.73E-03	1.92E-03	2.63E-03	3.09E-03
Total PCDD	9.47E-03	1.92E-03	3.07E-03	4.82E-03
FURANS				
2378 TCDF	1.12E-02	2.74E-03	6.14E-03	6.71E-03
Other TCDF	1.15E-01	1.67E-02	4.08E-02	5.76E-02
Penta-CDF	3.19E-02	ND(4.94E-04)	1.10E-02	1.43E-02
Hexa-CDF	1.30E-02	ND(6.31E-04)	ND(3.24E-03)	4.34E-03
Hepta-CDF	ND(3.67E-03)	ND(7.96E-04)	ND(3.07E-04)	.00E+00
Octa-CDF	5.92E-04	ND(1.37E-04)	ND(2.63E-04)	1.97E-04
Total PCDF	1.72E-01	1.95E-02	5.79E-02	8.32E-02

ND = not detected (detection limit in parentheses).
ug = 1.0E-06g
8760 operating hours per year

TABLE A.3.4a. SITE 4 (BLB-A)/INLET
DIOXIN/FURAN EMISSION FACTORS
(Dry Solids Feed Rate Basis)

Dioxin/Furan Isomer	Dioxin/Furan Emission Factors (ug/kg)			
	Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	ND(8.28E-05)	ND(8.18E-05)	ND(2.80E-04)	.00E+00
Other TCDD	ND(8.28E-05)	8.18E-05	ND(2.80E-04)	2.73E-05
Penta-CDD	ND(3.21E-04)	ND(9.81E-05)	ND(3.73E-04)	.00E+00
Hexa-CDD	5.18E-04	3.27E-04	ND(1.46E-03)	2.82E-04
Hepta-CDD	1.24E-03	8.18E-04	2.18E-03	1.41E-03
Octa-CDD	3.42E-03	2.62E-03	7.62E-03	4.55E-03
Total PCDD	5.18E-03	3.84E-03	9.80E-03	6.27E-03
FURANS				
2378 TCDF	ND(6.21E-05)	ND(3.27E-04)	ND(6.22E-04)	.00E+00
Other TCDF	1.04E-03	8.18E-04	1.55E-03	1.14E-03
Penta-CDF	1.35E-03	9.81E-04	ND(2.30E-03)	7.76E-04
Hexa-CDF	1.86E-03	1.64E-03	2.95E-03	2.15E-03
Hepta-CDF	1.04E-03	4.91E-04	1.40E-03	9.75E-04
Octa-CDF	3.11E-04	3.27E-04	ND(9.80E-04)	2.13E-04
Total PCDF	5.59E-03	4.25E-03	5.91E-03	5.25E-03

ND = not detected (detection limit in parentheses).
ug = 1.0E-06g
8760 operating hours per year

TABLE A.3.4b. SITE 4 (BLB-A)/OUTLET
DIOXIN/FURAN EMISSION FACTORS
(Dry Solids Feed Rate Basis)

Dioxin/Furan Isomer	Dioxin/Furan Emission Factors (ug/kg)			
	Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	ND(2.52E-04)	ND(7.06E-05)	ND(7.54E-05)	.00E+00
Other TCDD	ND(2.52E-04)	2.12E-04	ND(7.54E-05)	7.06E-05
Penta-CDD	ND(1.06E-04)	ND(8.47E-05)	ND(1.51E-04)	.00E+00
Hexa-CDD	6.51E-04	ND(2.26E-04)	ND(1.64E-04)	2.17E-04
Hepta-CDD	1.30E-03	3.53E-04	3.43E-04	6.66E-04
Octa-CDD	3.01E-03	1.55E-03	8.91E-04	1.82E-03
Total PCDD	4.96E-03	2.12E-03	1.23E-03	2.77E-03
FURANS				
2378 TCDF	ND(3.26E-05)	ND(1.41E-04)	ND(6.85E-05)	.00E+00
Other TCDF	1.38E-03	2.12E-04	1.37E-04	5.77E-04
Penta-CDF	6.51E-04	ND(1.62E-04)	ND(8.91E-05)	2.17E-04
Hexa-CDF	5.70E-04	2.12E-04	ND(3.49E-04)	2.60E-04
Hepta-CDF	8.14E-04	7.06E-04	2.06E-04	5.75E-04
Octa-CDF	3.26E-04	1.06E-03	6.85E-05	4.84E-04
Total PCDF	3.74E-03	2.19E-03	4.11E-04	2.11E-03

ND = not detected (detection limit in parentheses).
ug = 1.0E-06g
8760 operating hours per year

TABLE A.3.5a. SITE 5 (BLB-B)/INLET
DIOXIN/FURAN EMISSION FACTORS
(Dry Solids Feed Rate Basis)

Dioxin/Furan Isomer	Dioxin/Furan Emission Factors (ug/kg)			
	Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	ND(1.53E-04)	ND(2.47E-04)	ND(9.60E-05)	.00E+00
Other TCDD	ND(1.53E-04)	ND(2.47E-04)	ND(9.60E-05)	.00E+00
Penta-CDD	ND(1.53E-04)	ND(2.74E-05)	ND(3.43E-04)	.00E+00
Hexa-CDD	ND(1.53E-04)	ND(3.43E-04)	8.23E-04	2.74E-04
Hepta-CDD	6.81E-04	2.88E-03	2.69E-02	1.01E-02
Octa-CDD	2.72E-03	9.19E-03	1.35E-01	4.90E-02
Total PCDD	3.40E-03	1.21E-02	1.63E-01	5.94E-02
FURANS				
2378 TCDF	1.70E-04	ND(2.47E-04)	2.74E-04	1.48E-04
Other TCDF	1.70E-04	ND(2.47E-04)	1.78E-03	6.51E-04
Penta-CDF	ND(4.09E-04)	ND(1.37E-04)	ND(3.43E-04)	.00E+00
Hexa-CDF	3.40E-04	4.11E-04	9.60E-04	5.70E-04
Hepta-CDF	1.70E-04	1.37E-03	2.47E-03	1.34E-03
Octa-CDF	1.70E-04	9.60E-04	1.78E-03	9.71E-04
Total PCDF	1.02E-03	2.74E-03	7.27E-03	3.68E-03

ND = not detected (detection limit in parentheses).
ug = 1.0E-06g
8760 operating hours per year

TABLE A.3.5b. SITE 5 (BLB-B)/OUTLET
DIOXIN/FURAN EMISSION FACTORS
(Dry Solids Feed Rate Basis)

Dioxin/Furan Isomer	Dioxin/Furan Emission Factors (ug/kg)			
	Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	ND(1.19E-04)	ND(4.58E-05)	ND(1.02E-04)	.00E+00
Other TCDD	ND(1.19E-04)	ND(4.58E-05)	ND(1.02E-04)	.00E+00
Penta-CDD	ND(1.79E-04)	ND(1.28E-04)	ND(5.56E-04)	.00E+00
Hexa-CDD	7.46E-04	ND(3.30E-04)	2.78E-04	3.41E-04
Hepta-CDD	1.34E-03	6.42E-04	6.49E-04	8.78E-04
Octa-CDD	4.18E-03	2.11E-03	2.22E-03	2.84E-03
Total PCDD	6.27E-03	2.75E-03	3.15E-03	4.06E-03
FURANS				
2378 TCDF	ND(1.49E-04)	ND(1.56E-04)	9.27E-05	3.09E-05
Other TCDF	1.04E-03	ND(1.56E-04)	2.78E-04	4.41E-04
Penta-CDF	ND(1.09E-03)	ND(1.28E-04)	ND(5.56E-04)	.00E+00
Hexa-CDF	2.83E-03	ND(5.32E-04)	5.56E-04	1.13E-03
Hepta-CDF	1.04E-03	2.75E-04	3.71E-04	5.63E-04
Octa-CDF	2.98E-04	1.83E-04	1.85E-04	2.22E-04
Total PCDF	5.22E-03	4.58E-04	1.48E-03	2.39E-03

ND = not detected (detection limit in parentheses).
ug = 1.0E-06g
8760 operating hours per year

TABLE A.3.6a SITE 6 (WRI-A)/OUTLET
(Wire only)
DIOXIN/FURAN EMISSION FACTORS
(Total Feed Rate Basis)

Dioxin/Furan Isomer	Dioxin/Furan Emission Factors (ug/kg)			
	Run 01	Run 02	Run 06	Avg.
DIOXINS				
2378 TCDD	NR	NR	2.83E-04	2.83E-04
Other TCDD	1.05E-03	NR	3.77E-03	2.41E-03
Penta-CDD	NR	NR	6.23E-03	6.23E-03
Hexa-CDD	6.32E-03	NR	2.69E-02	1.66E-02
Hepta-CDD	6.50E-02	5.49E-02	4.24E-01	1.81E-01
Octa-CDD	3.15E-02	3.15E-02	3.84E-01	1.49E-01
Total PCDD	1.04E-01	8.64E-02	8.45E-01	3.56E-01
FURANS				
2378 TCDF	NR	NR	1.13E-03	1.13E-03
Other TCDF	7.94E-03	2.46E-02	4.96E-02	2.74E-02
Penta-CDF	1.08E-02	NR	8.10E-02	4.59E-02
Hexa-CDF	2.50E-02	8.11E-03	1.85E-01	7.26E-02
Hepta-CDF	9.68E-02	1.56E-01	7.74E-01	3.42E-01
Octa-CDF	5.51E-02	7.45E-02	3.04E-01	1.44E-01
Total PCDF	1.96E-01	2.63E-01	1.39E+00	6.33E-01

NR = not reported by Troika.
ND = not detected (detection limit in parentheses).
ug = 1.0E-06g
2080 operating hours per year

NOTE: Several recoveries for the MM5 train samples did not meet the quality assurance requirements for all four labelled compounds. Problems with method efficiency resulted from contamination present in the sample extracts and corresponding difficulties in achieving acceptable chromatographic separations. The reported analytical results may actually represent lower bounds on the true values. See Section 7.3.1 for more details.

TABLE A.3.6b SITE 6 (WRI-A)/OUTLET
(Wire and Transformers)
DIOXIN/FURAN EMISSION FACTORS
(Total Feed Rate Basis)

Dioxin/Furan Isomer	Dioxin/Furan Emission Factors (ug/kg)			
	Run 03	Run 04	Run 05	Avg.
DIOXINS				
2378 TCDD	1.16E-04	NR	6.31E-04	3.74E-04
Other TCDD	5.21E-04	3.28E-03	8.36E-03	4.05E-03
Penta-CDD	9.68E-03	NR	1.77E-02	1.37E-02
Hexa-CDD	1.12E-01	NRE+00)	3.01E-02	7.11E-02
Hepta-CDD	7.73E-01	1.53E-01	1.13E-01	3.47E-01
Octa-CDD	2.75E+00	1.55E-01	1.01E-01	1.00E+00
Total PCDD	3.65E+00	3.12E-01	2.71E-01	1.44E+00
FURANS				
2378 TCDF	9.27E-04	NR	4.42E-03	2.67E-03
Other TCDF	5.88E-02	1.34E-01	1.18E-01	1.04E-01
Penta-CDF	1.24E-01	NR	7.07E-02	9.74E-02
Hexa-CDF	4.00E-01	9.38E-02	1.15E-01	2.03E-01
Hepta-CDF	8.76E-01	6.56E-01	3.38E-01	6.23E-01
Octa-CDF	1.83E+00	3.39E-01	2.52E-01	8.07E-01
Total PCDF	3.29E+00	1.22E+00	8.97E-01	1.84E+00

NR = not reported by Troika.
ND = not detected (detection limit in parentheses).
ug = 1.0E-06g
2080 operating hours per year

NOTE: Several recoveries for the MM5 train samples did not meet the quality assurance requirements for all four labelled compounds. Problems with method efficiency resulted from contamination present in the sample extracts and corresponding difficulties in achieving acceptable chromatographic separations. The reported analytical results may actually represent lower bounds on the true values. See Section 7.3.1 for more details.

TABLE A.3.7a. SITE 7 (WFB-A)/INLET
DIOXIN/FURAN EMISSION FACTORS
(Wet Wood Feed Rate Basis)

Dioxin/Furan Isomer	Dioxin/Furan Emission Factors (ug/kg) Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	NR	4.39E-03	3.75E-03	4.07E-03
Other TCDD	6.04E-02	1.03E-01	1.46E-01	1.03E-01
Penta-CDD	NR	1.21E-01	1.37E-01	1.29E-01
Hexa-CDD	6.21E-02	1.21E-01	1.39E-01	1.07E-01
Hepta-CDD	1.15E-01	9.62E-02	7.80E-02	9.63E-02
Octa-CDD	1.11E-01	2.33E-02	2.04E-02	5.15E-02
Total PCDD	3.48E-01	4.70E-01	5.24E-01	4.91E-01
FURANS				
2378 TCDF	NR	2.74E-02	2.72E-02	2.73E-02
Other TCDF	3.76E-01	5.13E-01	5.60E-01	4.83E-01
Penta-CDF	5.94E-02	1.96E-01	1.98E-01	1.51E-01
Hexa-CDF	4.11E-02	6.99E-02	8.02E-02	6.37E-02
Hepta-CDF	1.66E-02	3.01E-02	2.62E-02	2.43E-02
Octa-CDF	ND(4.00E-02)	3.04E-03	2.72E-03	1.92E-03
Total PCDF	4.93E-01	8.40E-01	8.94E-01	7.52E-01

NR = not reported by Troika.
ND = not detected (detection limit in parentheses).
ug = 1.0E-06g
8760 operating hours per year

TABLE A.3.7b. SITE 7 (WFB-A)/OUTLET
DIOXIN/FURAN EMISSION FACTORS
(Wet Wood Feed Rate Basis)

Dioxin/Furan Isomer	Dioxin/Furan Emission Factors (ug/kg)			
	Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	7.60E-04	1.08E-03	1.12E-03	9.87E-04
Other TCDD	1.76E-01	2.55E-01	9.05E-02	1.74E-01
Penta-CDD	2.24E-01	2.33E-01	7.26E-02	1.77E-01
Hexa-CDD	2.30E-01	2.38E-01	7.44E-02	1.81E-01
Hepta-CDD	1.25E-01	1.80E-01	1.13E-01	1.39E-01
Octa-CDD	3.57E-02	4.54E-02	3.84E-02	3.98E-02
Total PCDD	7.92E-01	9.52E-01	3.90E-01	7.11E-01
FURANS				
2378 TCDF	4.94E-03	7.21E-03	6.71E-03	6.29E-03
Other TCDF	1.25E-01	2.07E-01	8.00E-02	1.37E-01
Penta-CDF	8.59E-02	1.22E-01	4.77E-02	8.52E-02
Hexa-CDF	5.40E-02	8.18E-02	1.31E-02	4.96E-02
Hepta-CDF	2.28E-02	3.77E-02	1.19E-02	2.41E-02
Octa-CDF	4.56E-03	3.06E-03	2.24E-03	3.29E-03
Total PCDF	2.97E-01	4.59E-01	1.62E-01	3.06E-01

ND = not detected (detection limit in parentheses).
ug = 1.0E-06g
8760 operating hours per year

TABLE A.3.8a. SITE 8 (BLB-C)/INLET
DIOXIN/FURAN EMISSION FACTORS
(Dry Solids Feed Rate Basis)

Dioxin/Furan Isomer	Dioxin/Furan Emission Factors (ug/kg)			
	Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	ND(.00E+00)	ND(.00E+00)	ND(.00E+00)	.00E+00
Other TCDD	4.68E-03	2.02E-03	2.29E-03	3.00E-03
Penta-CDD	5.94E-03	2.98E-03	2.67E-03	3.87E-03
Hexa-CDD	9.18E-03	6.35E-03	6.49E-03	7.34E-03
Hepta-CDD	8.10E-03	4.91E-03	4.58E-03	5.86E-03
Octa-CDD	5.40E-03	4.04E-03	4.01E-03	4.48E-03
Total PCDD	3.33E-02	2.03E-02	2.00E-02	2.45E-02
FURANS				
2378 TCDF	ND(.00E+00)	ND(.00E+00)	ND(.00E+00)	.00E+00
Other TCDF	3.56E-02	3.94E-03	4.20E-03	1.46E-02
Penta-CDF	3.40E-02	2.31E-03	ND(2.48E-03)	1.21E-02
Hexa-CDF	2.52E-02	3.17E-03	3.05E-03	1.05E-02
Hepta-CDF	6.66E-03	1.15E-03	9.54E-04	2.92E-03
Octa-CDF	9.00E-04	5.77E-04	ND(5.73E-04)	4.92E-04
Total PCDF	1.02E-01	1.12E-02	8.21E-03	4.06E-02

ND = not detected (detection limit in parentheses).
ug = 1.0E-06g
8760 operating hours per year

TABLE A.3.8b. SITE 8 (BLB-C)/OUTLET
DIOXIN/FURAN EMISSION FACTORS
(Dry Solids Feed Rate Basis)

Dioxin/Furan Isomer	Dioxin/Furan Emission Factors (ug/kg)			
	Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	ND(6.33E-05)	ND(3.19E-05)	ND(1.76E-05)	.00E+00
Other TCDD	3.17E-04	8.78E-04	4.40E-04	5.45E-04
Penta-CDD	ND(1.58E-04)	1.76E-03	7.04E-04	8.20E-04
Hexa-CDD	4.75E-04	3.35E-03	1.67E-03	1.83E-03
Hepta-CDD	7.92E-04	9.73E-03	3.35E-03	4.62E-03
Octa-CDD	1.90E-03	1.91E-02	3.17E-03	8.07E-03
Total PCDD	3.48E-03	3.49E-02	9.33E-03	1.59E-02
FURANS				
2378 TCDF	ND(9.50E-05)	1.28E-04	ND(1.76E-05)	4.26E-05
Other TCDF	7.92E-04	2.11E-03	2.38E-03	1.76E-03
Penta-CDF	ND(3.17E-04)	1.76E-03	3.35E-03	1.70E-03
Hexa-CDF	7.92E-04	1.84E-03	3.61E-03	2.08E-03
Hepta-CDF	6.33E-04	2.71E-03	2.64E-03	2.00E-03
Octa-CDF	3.17E-04	3.19E-04	3.52E-04	3.29E-04
Total PCDF	2.53E-03	8.86E-03	1.23E-02	7.91E-03

ND = not detected (detection limit in parentheses).
ug = 1.0E-06g
8760 operating hours per year

TABLE A.3.9a. SITE 9 (CRF-A)/INLET
DIOXIN/FURAN EMISSION FACTORS
(Bare Carbon Feed Rate Basis)

Dioxin/Furan Isomer	Dioxin/Furan Emission Factors (ug/kg)			
	Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	7.93E-04	6.17E-04	1.25E-03	8.86E-04
Other TCDD	1.43E-02	1.08E-02	4.34E-02	2.28E-02
Penta-CDD	3.13E-02	5.87E-03	3.53E-02	2.41E-02
Hexa-CDD	9.36E-02	3.61E-02	5.12E-02	6.03E-02
Hepta-CDD	1.23E-01	7.81E-02	5.58E-02	8.58E-02
Octa-CDD	1.42E-01	1.33E-01	2.99E-02	1.02E-01
Total PCDD	4.06E-01	2.64E-01	2.17E-01	2.96E-01
FURANS				
2378 TCDF	1.39E-02	1.45E-02	1.31E-02	1.38E-02
Other TCDF	1.89E-01	2.15E-01	1.97E-01	2.00E-01
Penta-CDF	1.36E-01	1.17E-01	1.76E-01	1.43E-01
Hexa-CDF	1.61E-01	1.53E-01	1.60E-01	1.58E-01
Hepta-CDF	1.13E-01	1.39E-01	1.26E-01	1.26E-01
Octa-CDF	5.19E-02	6.08E-02	4.87E-02	5.38E-02
Total PCDF	6.65E-01	6.99E-01	7.21E-01	6.95E-01

ND = not detected (detection limit in parentheses).
ug = 1.0E-06g
8760 operating hours per year

TABLE A.3.9b. SITE 9 (CRF-A)/OUTLET
DIOXIN/FURAN EMISSION FACTORS
(Bare Carbon Feed Rate Basis)

Dioxin/Furan Isomer	Dioxin/Furan Emission Factors (ug/kg)			
	Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	ND(4.18E-03)	ND(9.84E-04)	ND(1.03E-03)	.00E+00
Other TCDD	1.37E-02	ND(1.48E-03)	1.54E-03	5.09E-03
Penta-CDD	8.96E-03	2.46E-03	ND(2.57E-03)	3.81E-03
Hexa-CDD	1.43E-02	5.90E-03	4.62E-03	8.29E-03
Hepta-CDD	1.08E-02	6.39E-03	5.13E-03	7.43E-03
Octa-CDD	9.56E-03	5.41E-03	5.13E-03	6.70E-03
Total PCDD	5.74E-02	2.02E-02	1.64E-02	3.13E-02
FURANS				
2378 TCDF	ND(3.59E-03)	ND(2.95E-03)	ND(2.05E-03)	.00E+00
Other TCDF	1.25E-02	9.84E-03	7.19E-03	9.86E-03
Penta-CDF	3.59E-03	5.41E-03	ND(2.57E-03)	3.00E-03
Hexa-CDF	6.57E-03	3.94E-03	4.11E-03	4.87E-03
Hepta-CDF	7.77E-03	3.94E-03	3.59E-03	5.10E-03
Octa-CDF	5.38E-03	2.46E-03	5.65E-03	4.49E-03
Total PCDF	3.59E-02	2.56E-02	2.05E-02	2.73E-02

ND = not detected (detection limit in parentheses).
ug = 1.0E-06g
8760 operating hours per year

TABLE A.3.10. SITE 10 (MET-A)/OUTLET
DIOXIN/FURAN EMISSION FACTORS
(Coke-Free Feed Rate Basis)

Dioxin/Furan Isomer	Dioxin/Furan Emission Factors (ug/kg)			
	Run 02	Run 03	Run 04	Avg.
DIOXINS				
2378 TCDD	2.22E-01	9.05E-02	6.76E-02	1.27E-01
Other TCDD	4.46E-01	7.47E-01	6.33E-01	6.09E-01
Penta-CDD	7.94E-01	1.24E+00	8.73E-01	9.70E-01
Hexa-CDD	1.84E+00	1.15E+00	7.92E-01	1.26E+00
Hepta-CDD	1.38E+00	3.12E+00	1.74E+00	2.08E+00
Octa-CDD	8.23E-01	1.97E+00	1.24E+00	1.35E+00
Total PCDD	5.51E+00	8.32E+00	5.35E+00	6.39E+00
FURANS				
2378 TCDF	2.35E+00	2.70E+00	3.11E+00	2.72E+00
Other TCDF	7.94E+00	9.48E+00	1.56E+01	1.10E+01
Penta-CDF	7.07E+00	9.88E+00	8.96E+00	8.64E+00
Hexa-CDF	6.45E+00	3.24E+00	3.03E+00	4.24E+00
Hepta-CDF	2.28E+00	5.67E+00	2.31E+00	3.42E+00
Octa-CDF	1.55E+00	3.83E+00	2.16E+00	2.52E+00
Total PCDF	2.76E+01	3.48E+01	3.51E+01	3.25E+01

Note: emission factor is based on feed rate to cupola furnace (coke-free basis)
ND = not detected (detection limit in parentheses).
ug = 1.0E-06g
kg = 1.0E+03g
8160 operating hours per year

NOTE: Surrogate recoveries could not be determined for Run 02 and 04 dioxin/furan samples because of the relatively large quantities of native CDD and CDF species present in the samples. The reported analytical results may actually represent lower bounds on the true values. See Section 7.3.1 for more details.

TABLE A.3.11a. SITE 11 (DBR-A)/INLET
DIOXIN/FURAN EMISSION FACTORS
(Drum Feed Rate Basis)

Dioxin/Furan Isomer	Dioxin/Furan Emission Factors (ug/kg)			
	Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	2.90E-01	2.15E-01	1.20E-01	2.09E-01
Other TCDD	1.00E+00	7.39E-01	9.92E-01	9.12E-01
Penta-CDD	1.52E+00	6.43E-01	1.50E+00	1.22E+00
Hexa-CDD	1.48E+00	4.18E-01	2.59E+00	1.49E+00
Hepta-CDD	8.31E+00	1.73E-01	2.56E+00	3.68E+00
Octa-CDD	3.09E+00	1.46E-01	5.61E-01	1.26E+00
Total PCDD	1.57E+01	2.33E+00	8.32E+00	8.78E+00
FURANS				
2378 TCDF	8.42E-01	8.18E-01	6.09E-01	7.56E-01
Other TCDF	1.13E+01	8.11E+00	1.29E+01	1.08E+01
Penta-CDF	9.85E+00	4.12E+00	8.06E+00	7.34E+00
Hexa-CDF	2.53E+00	7.58E-01	4.41E+00	2.57E+00
Hepta-CDF	7.71E+00	3.16E-01	2.50E+00	3.51E+00
Octa-CDF	2.48E+00	7.29E-02	5.91E-01	1.05E+00
Total PCDF	3.48E+01	1.42E+01	2.90E+01	2.60E+01

ND = not detected (detection limit in parentheses).
ug = 1.0E-06g
1536 operating hours per year

NOTE: Several recoveries for the MM5 train samples did not meet the quality assurance requirements for all four labelled compounds. Problems with method efficiency resulted from contamination present in the sample extracts and corresponding difficulties in achieving acceptable chromatographic separations. The reported analytical results may actually represent lower bounds on the true values. See Section 7.3.1 for more details.

TABLE A.3.11b. SITE 11 (DBR-A)/OUTLET
DIOXIN/FURAN EMISSION FACTORS
(Drum Feed Rate Basis)

Dioxin/Furan Isomer	Dioxin/Furan Emission Factors (ug/kg)			
	Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	2.68E-03	1.18E-03	2.39E-03	2.09E-03
Other TCDD	6.44E-02	3.72E-02	4.30E-02	4.82E-02
Penta-CDD	5.90E-02	1.18E-02	1.67E-02	2.92E-02
Hexa-CDD	5.37E-02	1.77E-02	2.51E-02	3.22E-02
Hepta-CDD	9.66E-02	3.25E-02	3.11E-02	5.34E-02
Octa-CDD	5.37E-02	3.25E-02	2.63E-02	3.75E-02
Total PCDD	3.30E-01	1.33E-01	1.45E-01	2.03E-01
FURANS				
2378 TCDF	6.44E-02	2.36E-02	2.15E-02	3.65E-02
Other TCDF	6.79E-01	6.40E-01	4.40E-01	5.86E-01
Penta-CDF	4.00E-01	1.92E-01	1.66E-01	2.53E-01
Hexa-CDF	1.99E-01	9.46E-02	7.29E-02	1.22E-01
Hepta-CDF	1.37E-01	6.21E-02	4.78E-02	8.22E-02
Octa-CDF	3.76E-02	1.77E-02	1.19E-02	2.24E-02
Total PCDF	1.52E+00	1.03E+00	7.60E-01	1.10E+00

ND = not detected (detection limit in parentheses).
ug = 1.0E-06g
1536 operating hours per year

TABLE A.3.12a. SITE 12 (SSI-C)/INLET
DIOXIN/FURAN EMISSION FACTORS
(Dry Solids Feed Rate Basis)

Dioxin/Furan Isomer	Dioxin/Furan Emission Factors (ug/kg)			
	Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	NR	NR	NR	NR
Other TCDD	NR	3.27E-02	7.34E-02	5.31E-02
Penta-CDD	NR	ND(1.85E-02)	4.19E-03	2.10E-03
Hexa-CDD	NR	6.68E-02	5.77E-02	6.23E-02
Hepta-CDD	NR	5.06E-01	1.70E-01	3.38E-01
Octa-CDD	NR	5.55E-01	1.90E-01	3.73E-01
Total PCDD	NR	1.16E+00	4.96E-01	8.29E-01
FURANS				
2378 TCDF	NR	3.87E-01	6.84E-01	5.36E-01
Other TCDF	NR	9.39E-01	1.02E+00	9.80E-01
Penta-CDF	NR	8.44E-01	9.16E-01	8.80E-01
Hexa-CDF	NR	9.60E-02	8.60E-02	9.10E-02
Hepta-CDF	NR	9.19E-01	1.00E-01	5.10E-01
Octa-CDF	NR	9.22E-01	1.15E-01	5.19E-01
Total PCDF	NR	4.11E+00	2.92E+00	3.52E+00

NR = not reported by Troika.
ND = not detected (detection limit in parentheses).
ug = 1.0E-06g
8760 operating hours per year

NOTE: Several recoveries for the MM5 train samples did not meet the quality assurance requirements for all four labelled compounds. Problems with method efficiency resulted from contamination present in the sample extracts and corresponding difficulties in achieving acceptable chromatographic separations. The reported analytical results may actually represent lower bounds on the true values. See Section 7.3.1 for more details.

TABLE A.3.12b. SITE 12 (SSI-C)/OUTLET
DIOXIN/FURAN EMISSION FACTORS
(Dry Solids Feed Rate Basis)

Dioxin/Furan Isomer	Dioxin/Furan Emission Factors (ug/kg)			
	Run 01	Run 02	Run 03	Avg.
DIOXINS				
2378 TCDD	8.12E-04	9.31E-04	1.07E-03	9.37E-04
Other TCDD	4.39E-02	6.29E-02	5.44E-02	5.37E-02
Penta-CDD	4.64E-03	7.98E-03	9.06E-03	7.23E-03
Hexa-CDD	3.08E-02	6.32E-02	4.74E-02	4.71E-02
Hepta-CDD	4.53E-02	2.94E-01	1.04E-01	1.48E-01
Octa-CDD	3.71E-02	1.98E-01	8.32E-02	1.06E-01
Total PCDD	1.62E-01	6.27E-01	3.00E-01	3.63E-01
FURANS				
2378 TCDF	3.54E-01	3.71E-01	3.29E-01	3.52E-01
Other TCDF	7.86E-01	1.19E+00	1.00E+00	9.94E-01
Penta-CDF	5.85E-01	7.73E-01	7.19E-01	6.92E-01
Hexa-CDF	9.69E-02	3.47E-01	2.20E-01	2.21E-01
Hepta-CDF	4.53E-02	9.50E-01	2.94E-01	4.30E-01
Octa-CDF	2.09E-02	7.38E-01	2.16E-01	3.25E-01
Total PCDF	1.89E+00	4.37E+00	2.78E+00	3.01E+00

ND = not detected (detection limit in parentheses).
ug = 1.0E-06g
8760 operating hours per year

APPENDIX A.4

Error Analysis: Control Device Efficiency Calculations

APPENDIX A.4
ERROR ANALYSIS: CONTROL DEVICE EFFICIENCY CALCULATIONS

Objective: Given the analytical uncertainty of the CDD/CDF analyses (± 50% accuracy), estimate the uncertainty of the control device efficiency calculations.

Let: $C_{out,meas}$ = the measured concentration of a given CDD/CDF homologue at the outlet location.

$C_{in,meas}$ = the measured concentration of a given CDD/CDF homologue at the inlet location.

$C_{out,max}$ = the maximum possible concentration of the CDD/CDF homologue given the measured value $C_{out,meas}$.

$C_{out,min}$ = the minimum possible concentration of the CDD/CDF homologue given the measured value $C_{out,meas}$.

$C_{in,max}$ = the maximum possible concentration of the CDD/CDF homologue, given the measured value $C_{in,meas}$.

$C_{in,min}$ = the minimum possible concentration of the CDD/CDF homologue, given the measured value $C_{in,meas}$.

E = the removal efficiency of the control device

Assuming ± 50 percent analytical accuracy:

$$C_{min} = C_{meas} - 0.5\ C_{meas} = 0.5\ C_{meas}$$

$$C_{max} = C_{meas} + 0.5\ C_{meas} = 1.5\ C_{meas}$$

Note that: $$E_{max} = \frac{C_{in,max} - C_{out,min}}{C_{in,max}} = 1 - \frac{C_{out,min}}{C_{in,max}}$$

$$E_{max} = 1 - \frac{0.5\ C_{out,meas}}{1.5\ C_{in,meas}} = 1 - {}^{1}/_{3}\,(1 - E_{meas})$$

$$= {}^{2}/_{3} + {}^{1}/_{3}\,E_{meas}$$

and:

$$E_{min} = \frac{C_{in,min} - C_{out,max}}{C_{in,min}} = 1 - \frac{C_{out,max}}{C_{in,min}}$$

$$= 1 - \frac{1.5\ C_{out,meas}}{0.5\ C_{in,meas}}$$

$$= 1 - 3\ (1 - E_{meas})$$

$$E_{min} = 3\ E_{meas} - 2$$

Now, $E_{min} > 0$ ⇒ positive control (i.e., emissions reduction across the control device)

$$(3E_{meas} - 2) > 0$$

$$E_{meas} > {}^{2}/_{3}$$

Therefore, if E_{meas} is larger than 66.7 percent, the true removal efficiency can safely be assumed to be greater than zero.

And, $E_{max} < 0$ ⇒ negative control (i.e., emissions increase across the control device)

$${}^{2}/_{3} + {}^{1}/_{3}\ E_{meas} < 0$$

$$E_{meas} < -2$$

Therefore, if E_{meas} is less than -200 percent, the true efficiency can safely be assumed to be less than zero.

To summarize:

$E_{meas} > 66.7$ percent ⇒ positive control

$-200 < E_{meas} < 66.7$ percent ⇒ no definitive conclusions can be drawn

$E_{meas} < 200$ percent ⇒ negative control

TABLE A.4 VALUES OF E_{max} and E_{min} FOR VARIOUS MEASURED CONTROL EFFICIENCIES

Control Device Efficiency (%)		
E_{meas}	E_{max}	E_{min}
100	100	100
95	98.3	85
90	96.7	70
85	95.0	55
80	93.4	40
75	91.7	25
50	83.4	-50
25	75.0	-125
0	66.7	-200
-25	58.4	-275
-50	50.0	-350
-100	33.4	-500
-200	0	-800

$$E_{max} = (200 + E_{meas})/3$$

$$E_{min} = 3E_{meas} - 200$$